Conceptual Framework for the Development of Long-term Monitoring Protocols at Mammoth Cave National Park, Kentucky

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SUMMARY

Mammoth Cave serves as the prototype monitoring park for cave and karst ecosystems and biome. The history and basis of MACA's development into the cave and karst prototype is reviewed. The USGS-BRD, in cooperation with the NPS, is charged with designing and testing monitoring protocols for implementation under the Long-term Ecological Monitoring (LTEM) Program at MACA.

This document presents a conceptual framework for the development of monitoring protocols for the MACA LTEM program. The MACA LTEM Program is ecosystem-based and issue-oriented, and focuses on multi-parameter monitoring of ecological process pathways among MACA's major component ecosystems. This ecosystem pathway perspective emphasizes attaining an understanding of the spatial and temporal ecosystem dynamics through attaining diverse understanding of the functional connections that tie together MACA's ecosystems. The issues-oriented emphasis acknowledges the existence of natural and anthropogenic threats to ecosystem function and stability, and provides science-based support for management decision-making processes that focus on reducing or eliminating these threats.

Three major ecosystems are described for MACA (a terrestrial/forest system, a river-aquatic/fluvial system based upon the Green River within MACA, and a composite cave ecosystem with cave-terrestrial and cave-river components). Conceptual "effects" models were developed to outline the complex functional pathways that tie together the three MACA ecosystems, and to place in functional perspective ecosystem components and potential threats and Agents of Change (natural and human process and activities that can potentially alter ecosystem function). The models serve as visual guidance in the process of selecting major ecosystem pathways, system attributes and potential Agents of Change that could be considered for monitoring within the LTEM program. The MACA LTEM team, with assistance from outside technical experts, selected several "key" pathways for initial programmatic focus. The ecosystem attributes associated with these pathways were then subjected to a ranking and sorting process that identified a list of high-priority attributes which will be the focus of monitoring protocol development.

Part One of this plan presents a conceptual framework as an objective basis for selecting monitoring components of the MACA LTEM Program. Part Two presents summaries of the monitoring protocols that are under development and/or proposed for development within the program, including statements of the problems being addressed, lists of monitoring questions, the general monitoring approach, and a statement of management applications. Finally, Part Three summarizes data management efforts.

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INTRODUCTION

A. Overview of the Prototype Long-Term Ecological Monitoring Program

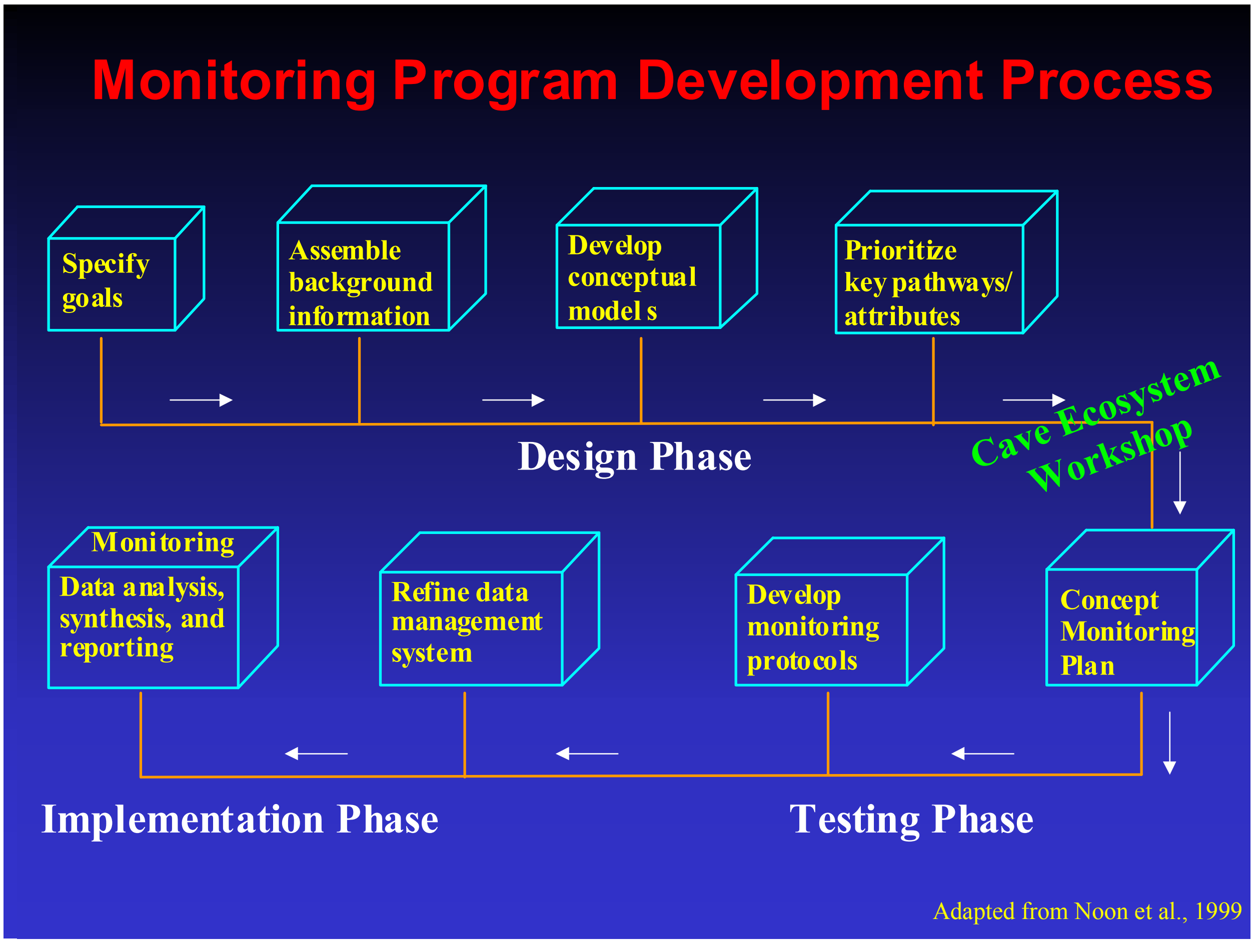
In the early 1990s, the National Park Service (NPS) initiated a series of prototype Long-Term Ecological Monitoring (LTEM) programs to gain experience with natural resource monitoring. The first four prototype monitoring programs (CHIS, DENA, GRSM, and SHEN) were funded in 1992. In 1993 the Washington office issued a Call for Proposals to competitively select seven additional prototype monitoring programs. The goal was to maximize the experience gained from the pilot programs by representing the major biogeographic regions and a range of park sizes. Mammoth Cave prototype was one of seven programs selected through this competition with initial funding provided in FY 2001. Mammoth Cave (MACA) serves as the prototype monitoring park for cave and karst ecosystems and biome.

The 1993 MACA LTEM proposal focused exclusively on monitoring cave resources, surface water quality, surface water benthic macroinvertebrates, and adjacent land use. Due to a shift of focus on understanding ecosystems from an integrated and functional perspective that addresses a broad array of management issues/stressors, and with guidance from the Servicewide I & M leadership, the MACA LTEM program has expanded to include monitoring additional biotic elements of the riverine and surface terrestrial (largely forest) ecosystems. These additional components are important resources to park management, have broad Vital Signs Network and even Servicewide application, and contribute to our functional understanding of the cave ecosystem.

The purpose of the MACA LTEM program is to provide park resource managers with science-based status and trend information to support the NPS mission of conserving park resources unimpaired. Thus the program will be ecosystem-based and issues-oriented, and focuses on multi-parameter monitoring of ecological process pathways among MACA's major component ecosystems. The LTEM program will monitor park natural resources to: 1) determine status and track trends in selected attributes as indicators of the condition of park ecosystems, 2) provide early warning of abnormal changes in conditions of selected resources, 3) provide data to better understand the dynamic nature and function of park ecosystems, 4) provide data to meet legal mandates related to natural resource protection and visitor enjoyment, 5) provide science-based information to support the park resource management decision-making process, and 6) asses the consequences of the park's management on the natural resources. In order to meet these objectives, the LTEM program will develop and implement long-term monitoring protocols for several resources.

The U. S. Geological Survey-Biological Resources Division (USGS-BRD), in cooperation with the NPS, is charged with designing and testing monitoring protocols for implementation under the LTEM program at MACA. For the first four years of the program's development (FY 2002 – FY 2006) the USGS's Leetown Science Center has stationed a scientist at the park to provide technical assistance with programmatic development and to take the lead on producing sampling protocols for the park. The National Park Service will be responsible for implementing the program and protocols. Development of the MACA prototype program will follow the general process adapted from Noon et. al., (1999). The MACA process departs from Noon's (1999) process in that it includes parallel performance of several steps rather than a strictly stepwise progression (Figure 1).

Figure 1. The Mammoth Cave prototype program development process.



The operational structure of the program consists of dedicated staff under the leadership of a program coordinator. It functions as a program within MACA's Division of Science and Resources Management (SRM), with 261K of program funding permanently transferred to MACA ONPS base and 200K of program funding arriving as project monies at least through the program development phase. The SRM Division Chief supervises the program. The program staff consists of a program coordinator, all or part of 6 permanent professional positions, and 5 student interns (via a cooperative agreement with nearby Western Kentucky University) (Figure 2). Six SRM base-funded permanent staff contribute to the program on a collaborative basis and form an integrated team with the program to maximize use of available expertise (e.g., SRM's base-funded hydrologist will lead implementation of water quality monitoring protocols, and the SRM aquatic biologist will take the lead on implementing the fish and mussel diversity protocols). Table 1 details the program's estimated fiscal year 2004 personnel cost budget.

In FY 2000, through the Natural Resource Challenge, the National Park Service launched the Core Park Vital Signs Monitoring Program. This effort will initiate monitoring of significant natural resources in all 270 park units by FY 2004. Parks are being organized into 32 geography-based networks in order to maximize monitoring efficiency. While funding is currently insufficient to implement comprehensive natural resource monitoring, the network approach will provide consistent funding to initiate core monitoring programs in all parks..

Figure 2. Mammoth Cave Prototype LTEM Program Organization Chart & Current Staff.

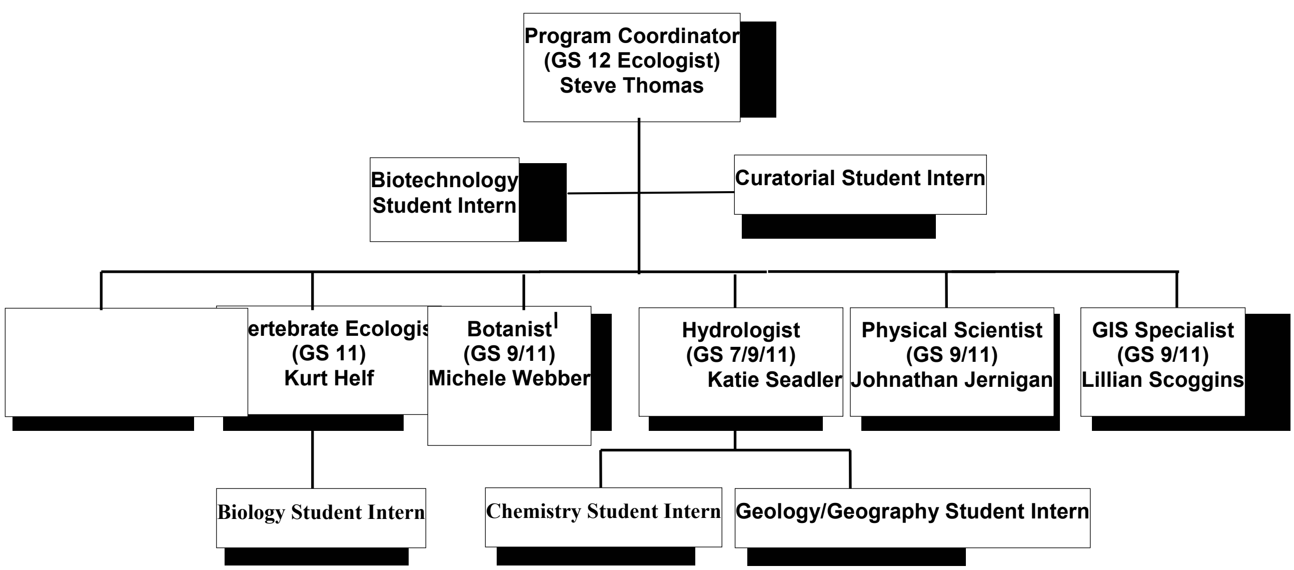


Table 1. Mammoth Cave Prototype LTEM Program's FY 2004 estimated annual personnel costs.

Personnel	
Program Coordinator (GS 12)	$84,500
Ecologist/Data Manager (GS 11/12)	$77,000
Invertebrate Ecologist (GS 11)	$72,000
Botanist (GS 9/11)	$48,000
GIS Specialist (GS 9/11)	$44,500
Physical Scientist (GS 9/11) [50% ARD]	$32,000
Hydrologist (GS 7/9/11) [75% CUPN]	$14,000
4 Student Interns via cooperative agreement with Western Kentucky University (20 hrs/wk during school year and 40 hrs/wk during summer)	$26,000
Total	**$398,000**

The Servicewide I&M leadership has recently decided that the seven funded prototype LTEM programs will continue to be funded at current levels and will serve as "centers of excellence" (or a similar term TBD), maintaining more in-depth monitoring efforts and continuing research and design work to benefit other park and mentor and support other parks. The prototype programs will benefit the developing networks by 1) providing mentoring assistance to other parks undertaking long-term ecological monitoring; 2) advising and providing technical assistance to staff from other parks on a wide range variety of technical issues related to monitoring including conceptual design, database management, data integration and analysis, and reporting of monitoring findings; and 3) producing exportable monitoring protocols, including ecoregion-specific methodologies and technical guidance (e.g. sampling design, power analysis, instructions on use of the products).

To support this new role for prototype monitoring programs within the network framework the MACA prototype LTEM program has begun reciprocal interactions with the Cumberland Piedmont Network (CUPN), and to a lesser degree, the Appalachian Highlands Network (APHN) as well. Some examples include: 1) the MACA prototype participated in the scoping meetings for both networks in FY 2002, 2) the MACA prototype coordinator serves on the Technical Committee for both networks and has provided technical assistance with network inventories, 3) the prototype is sharing the costs of operating and staffing the park's water quality analysis laboratory with the CUPN, 4) the prototype park is included in the CUPN's water quality monitoring protocol, 5) the prototype and CUPN have discussed the possibility of collaborating on database system development efforts in order to insure compatibility, 6) the CUPN coordinator participated in the MACA prototype attribute ranking process and in the park's Cave Ecosystem Workshop, and 7) MACA prototype and SRM staff have exported their attribute ranking and prioritization process to both networks and have provided technical assistance by participating in the process at most of the network parks and by providing follow-up analysis support.

The MACA prototype program will seek to integrate with the soon-to-be-funded Mammoth Cave International Center for Science and Learning. This Learning Center will be located on the park at the Maple Springs Research Complex. The Learning Center's research director will work closely with the LTEM program to link up qualified outside researchers with research questions generated through long-term monitoring using a "research catalog". Also, the education specialist associated with the Learning Center will likely be useful in assisting the prototype with disseminating monitoring results to targeted audiences.

This document will serve as an update to the original 1993 MACA LTEM proposal. Part One of this plan presents a conceptual framework as an objective basis for selecting monitoring components of the MACA LTEM Program. Part Two presents summaries of the monitoring protocols that are under development and/or proposed for development within the program, including statements of the problems being addressed, lists of monitoring questions, the general monitoring approach, and a statement of management applications. Finally, Part Three summarizes data management efforts.

B. Natural Resources and Anthropogenic Stressors

Mammoth Cave National Park, the Cave & Karst Ecosystem Prototype Park

Mammoth Cave National Park was selected as the cave and karst prototype in the NP Service's constellation of park units in 1994. This selection recognizes MACA's essential geographic and geological character, a cave system embedded in a karst landscape. Karst landscapes, characterized by rapid subsurface drainage through cave systems, account for approximately 15% of Earth's land surface, 25% of the continental United States, and 45% of the area east of the Mississippi River. A corresponding 25% of the global population resides in karst regions (Ford and Williams, 1989), and fully 40% of the U.S. population relies upon karst aquifers for drinking water. Nearly every state in the Union has karst topography, and within our National Park System, 120 Units have karst or cave resources (81 with caves, 39 with karst only).

Mammoth Cave National Park, containing the longest known cave system in the world (current total survey is approximately 579 kilometers long), is part of the South Central Kentucky Karst, which has been intensively studied by dye tracing, cave mapping, and continuous water quality and stage monitoring (Quinlan and Ewers 1989). Mammoth Cave itself is embedded within subterranean drainage basins covering more than 1050 square kilometers (400 square miles). The Cave Research Foundation has been mapping MACA's caves for over forty years and it has been estimated that less than half have been discovered and charted. Mammoth Cave National Park was designated a World Heritage Site by the United Nations Educational and Scientific and Cultural Organization (UNESCO) in 1981, and declared an International Biosphere Reserve by UNESCO in 1990, in recognition of both its geological uniqueness and its significant biodiversity.

Physiographic Overview

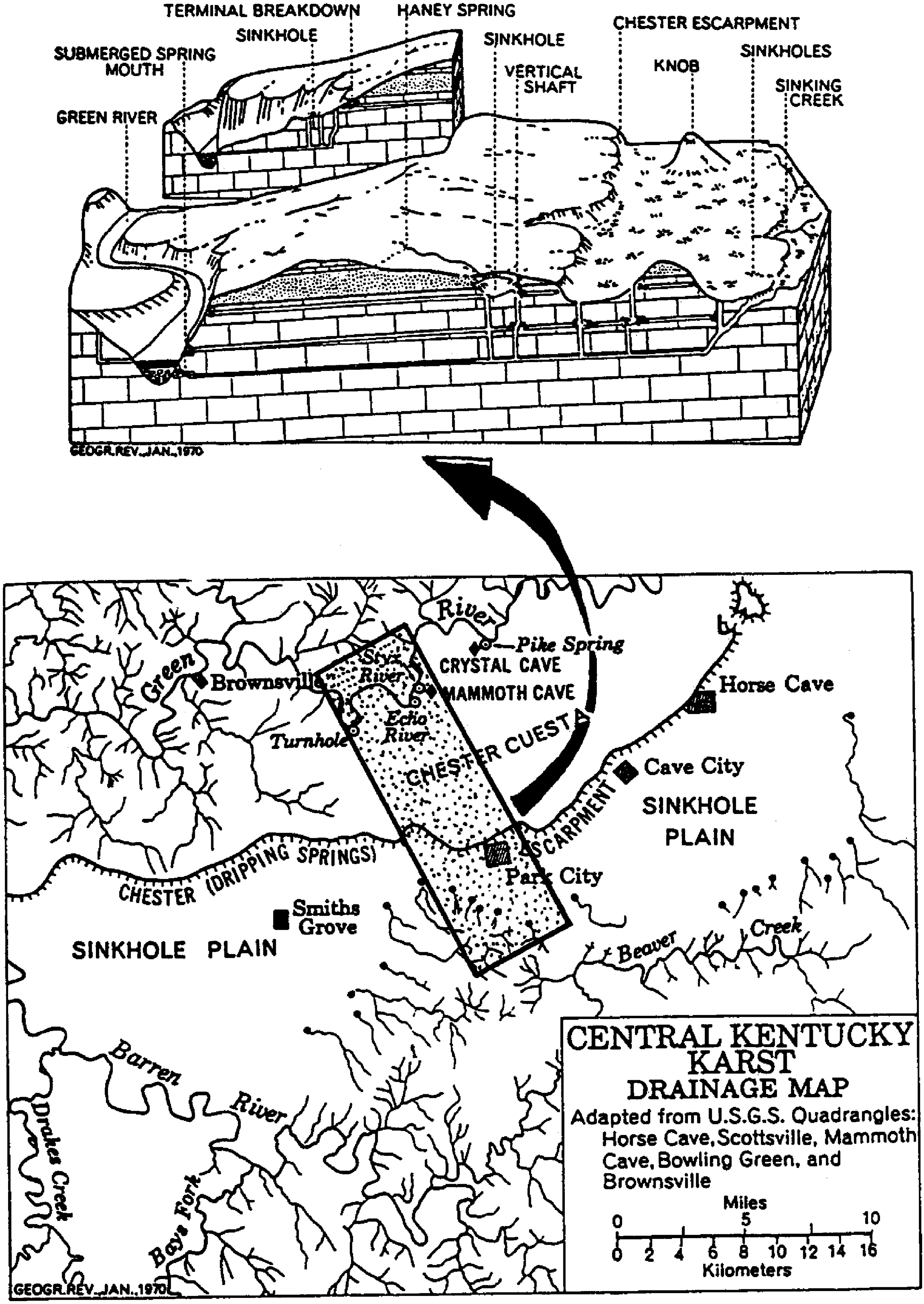
There are two major dividing lines running east-west across the region: the Chester Escarpment south of the park, and Green River within the park**.** The Chester Escarpment is the boundary between the Sinkhole Plain to the south, and the Mammoth Cave Plateau to the north (Figure 3). Both areas are underlain by the major cave bearing carbonates, but the plateau is capped by alternating sandstone and limestone bedrock units. This layer cake "caprock" as it is called, has its own karst drainage systems perched above the major regional karst system. This is important for two reasons: first, springs and upland swamps in a landscape otherwise lacking surface water are created, and second, shale in the Big Clifty sandstone sheds water and protects passages in the underlying limestone.

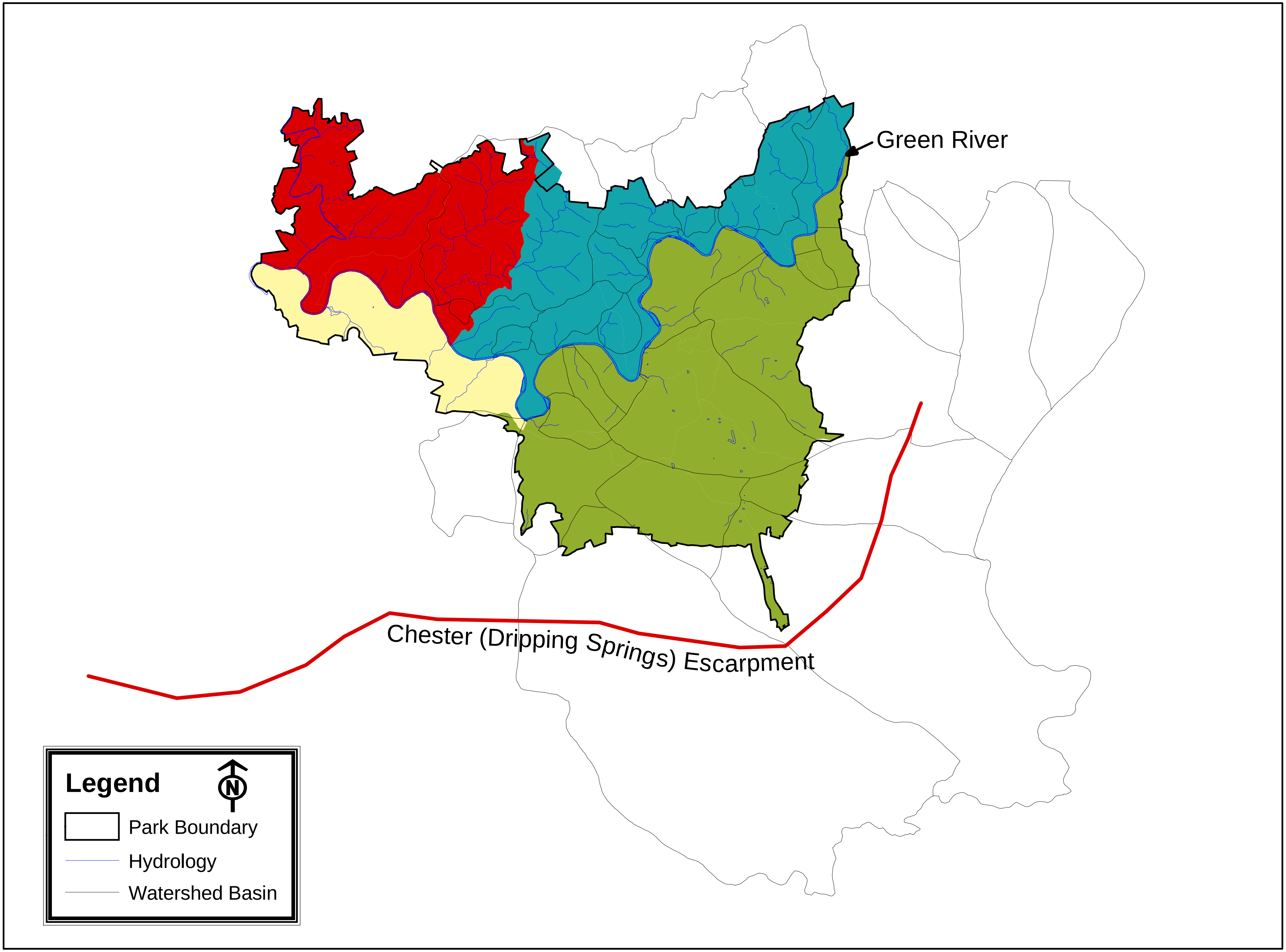
The park is physically divided into northern and southern halves by the Green River, which is the hydrologic base level for drainage within the park. Each half is then further divided east-west on the basis of karst development. Park lands south of Green River can most reasonably be divided at the western border of Turnhole Spring Basin (Figure 4). East of this dividing line, the park is characterized by the world class karst the Mammoth Cave area is famous for. Perennial surface streams are very limited in extent, and the area is well drained except for isolated sinkhole ponds, upland swamps, and short spring runs. The Mammoth Cave Plateau in this quadrant is highly dissected by large karst valleys equivalent in habitat type to the Sinkhole Plain. The drainage basins extend well beyond park boundaries where a range of land uses pose different threats. West of Turnhole Spring Basin, karst development is limited to sinking springs in the caprock with small catchments, and only minor cavernous development in the underlying massive limestone beds has taken place. The Mammoth Cave Plateau in this area is intact with no karst valleys, and because much of the drainage flows toward Beaverdam Creek instead of the Green River, the streams in this section of the park are small.

Karst development in the park north of Green River can most reasonably be divided along the western edge of Buffalo Creek's Dry Prong catchment. West of the Dry Prong, karst development is limited in much the same way as described for the area west of Turnhole Spring Basin on the south side. Significant perennial surface streams tributary to the Nolin River, such as Bylew and Second Creeks, have cut spectacular sandstone gorges that dissect the landscape more than any other area in the park. From Dry Prong of Buffalo Creek to the east park boundary, karst development has created several significant cave systems north of Green River, and Buffalo Creek Cave, which takes the flow of the Dry Prong, is westernmost. With the exception of Cub Run, which is aligned with a major fault, surface streams are limited to small segments that originate at springs perched on sandstone, and short spring runs on Green River.

Mammoth Cave; One Park, Several Ecosystems

Mammoth Cave National Park must be viewed in context of the South-Central Kentucky Karst, where there are two historical and four functioning ecosystems. In pre-settlement times, prairie and savanna maintained by fire were prevalent, and these ecosystems were converted to agriculture over the past two centuries. Much of the landscape surrounding MACA remains a greatly-altered agricultural ecosystem to this day. By comparison, on the park, MACA's forest-based terrestrial, river-based aquatic, the terrestrial and aquatic cave ecosystems are intact and largely functional, though significantly distorted in many respects.


TERMINAL BREAKDOWN
HANEY SPRING
SINKHOLE
SUBMERGED SPRING MOUTH
GREEN RIVER
SINKHOLE
VERTICAL SHAFT
CHESTER ESCARPMENT
KNOB
SINKHOLES
SINKING CREEK
GEOGR.REV., JAN., 1970
Green River
Brownsville
Styx River
Echo River
Turnhole
Pike Spring
CRYSTAL CAVE
MAMMOTH CAVE
CHESTER CUESTA
Horse Cave
Cave City
SINKHOLE PLAIN
CHESTER (DRIPPING SPRINGS) ESCARPMENT
Park City
Smiths Grove
SINKHOLE PLAIN
Beaver Creek
Barren River
Drakes Creek
Bays Fork
CENTRAL KENTUCKY KARST
DRAINAGE MAP
Adapted from U.S.G.S. Quadrangles: Horse Cave, Scottsville, Mammoth Cave, Bowling Green, and Brownsville
Miles
0 5 10
0 2 4 6 8 10 12 14 16
Kilometers
GEOGR.REV., JAN., 1970



Green River
Chester (Dripping Springs) Escarpment
Legend
N
Park Boundary
Hydrology
Watershed Basin

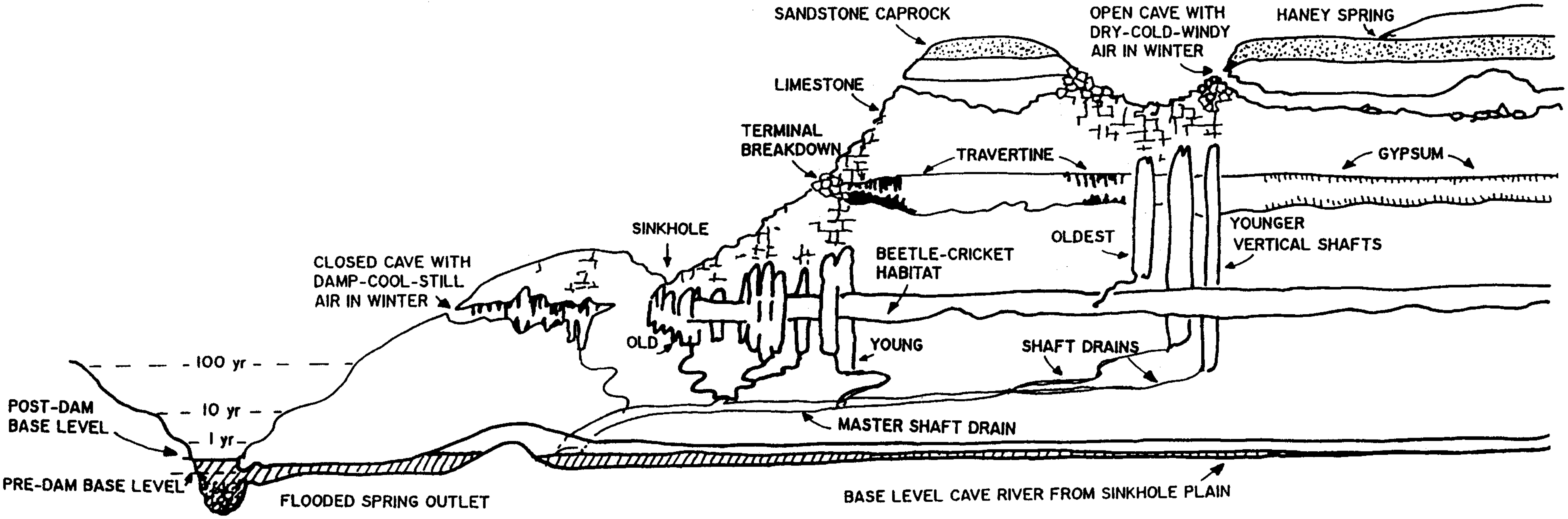
1. Mammoth Cave National Park's cave ecosystem and some major stressors

Mammoth Cave National Park includes, as a major set of resources, a significant and special ecosystem; that found in its name-sake cave system. Functionally, the cave ecosystem may be described as being two essentially un- (or only weakly) connected ecosystems- a cave "terrestrial system" located on nominally drier cave substrates and surfaces, and a distinctly "cave-river-based cave-aquatic system". For our purposes, this distinction will be made only where appropriate to distinguish and describe specific attributes. Mammoth Cave's cave-associated biota are among the most diverse in the world (Culver *et al.* 1999), with approximately 130 regularly occurring species roughly divided between troglobites, trolophiles, and trogloxenes (Barr, 1967 Poulson 1992, 1993). Troglobites are fully cave adapted, and cannot survive in surface habitats. Aquatic troglobites are also referred to as stygobites. Troglophiles are species that can complete their life cycle in both cave and surface habitats, and trogloxenes use caves for refuge or may come in to prey upon other species.

As shown in Figure 5, the passage types and resources are zoned horizontally and vertically within Mammoth Cave. The great range of cave zones substantially accounts for the high diversity of habitats and species. For aquatic habitats, food supply decreases, stream size increases, chances of flooding increase, and substrates change from rocks and gravel to sands and silt, one goes from upper to lower levels. Terrestrial habitats range from relatively rich to uninhabited areas so dry that they have been called "The Great Kentucky Desert". Food supply, air movement, and moisture change horizontally in complicated ways depending on position, entrance effects, and the sandstone caprock. There are many examples of closely related species in the Mammoth Cave Region that can coexist by occupying different ecological niches. It is common to find two species in a genus, for example, isopods, amphipods, flatworms, fungus gnats, or pseudoscorpions, to be found occupying the same niche. At the extreme, the coexistence of six species of carabid beetle and three species of amblyopsid fish is unparalleled.

In part, the Mammoth Cave Region cave terrestrial fauna is rich because the usual food sources such as plant debris, plankton, and bacteria introduced by water are supplemented by the feces of trogloxenic species that feed outside but rest and reproduce underground. There are different invertebrate communities based on raccoon, woodrat, and cave cricket feces. Of these trogloxenes, the cave cricket is most important because it is ubiquitous and locally abundant. From cave entrance roosts where they grow to deep cave areas where they reproduce there is a continuous gradient of cricket feces density and renewal rates. A corresponding gradient of other cave species that utilize this reliable food supply exists. Finally, there is an additional community centered on cricket eggs and feces of a beetle that eat the eggs.

Much of the subsurface invertebrate fauna in Edmonson County, one of only five biodiversity hotspots for subsurface invertebrate fauna in the United States (Culver et al. 2000), is found in the large concentration of caves within Mammoth Cave National Park (MACA) (Figure 6). MACA's subsurface invertebrate communities have both terrestrial and aquatic components; some members of these communities (i.e., troglobites and stygobites) have relatively small populations and can be restricted in their distribution. MACA's troglobite and stygobite communities are limited by the amount of organic input they receive from the surface.


SANDSTONE CAPROCK
OPEN CAVE WITH
DRY-COLD-WINDY
AIR IN WINTER
HANEY SPRING
LIMESTONE
TERMINAL
BREAKDOWN
TRAVERTINE
GYPSUM
SINKHOLE
OLDEST
YOUNGER
VERTICAL SHAFTS
CLOSED CAVE WITH
DAMP-COOL-STILL
AIR IN WINTER
BEETLE-CRICKET
HABITAT
OLD
YOUNG
SHAFT DRAINS
100 yr
10 yr
1 yr
POST-DAM
BASE LEVEL
MASTER SHAFT DRAIN
PRE-DAM BASE LEVEL
FLOODED SPRING OUTLET
BASE LEVEL CAVE RIVER FROM SINKHOLE PLAIN

The Mammoth Cave Ecosystem is summarized in the General Cave Ecosystem Effects model presented in Figure 10.

The cave cricket guano-based communities

A significant portion of the cave ecosystem's biota is found in the dependent invertebrate communities associated with feces ("guano") deposited into the cave ecosystem by the cave cricket, *Hadenoecus subterraneus.* Long-term population dynamics of subsurface invertebrate communities subsidized by cave crickets in MACA are ultimately driven by cave crickets' occasional nocturnal foraging bouts on the surface. Cave crickets spend most of their time roosting on cave ceilings where they digest their food and deposit guano on substrates below. Previous research suggested long-term (>20 yr) fluctuations in the abundance and diversity of invertebrates directly dependent on these guano deposits (e.g., the collembolan *Lepidocyrtus* and the mite *Ceratozetes*) (Poulson et al. 1995). Presumably, these limitations also apply to the population dynamics of the community comprised of energy efficient detritivores and their predators (e.g., the dipluran *Litocampa* and the spider *Anthrobia*) that feed on guano sparsely deposited over substrates where crickets walk from the entrance areas to the reproductive areas (Poulson 1992). Finally, a third community is found in areas with sand or silt substrate where the crickets mate and lay their eggs. Here the crickets indirectly support a community of detritivores and their predators (e.g. the collembolan *Arrhopalites* and the psuedoscorpion *Kleptochthonius*). via the feces of a carabid beetle (*Neaphaenops tellkampfi*) that specializes on eating cave cricket eggs (Poulson 1992).

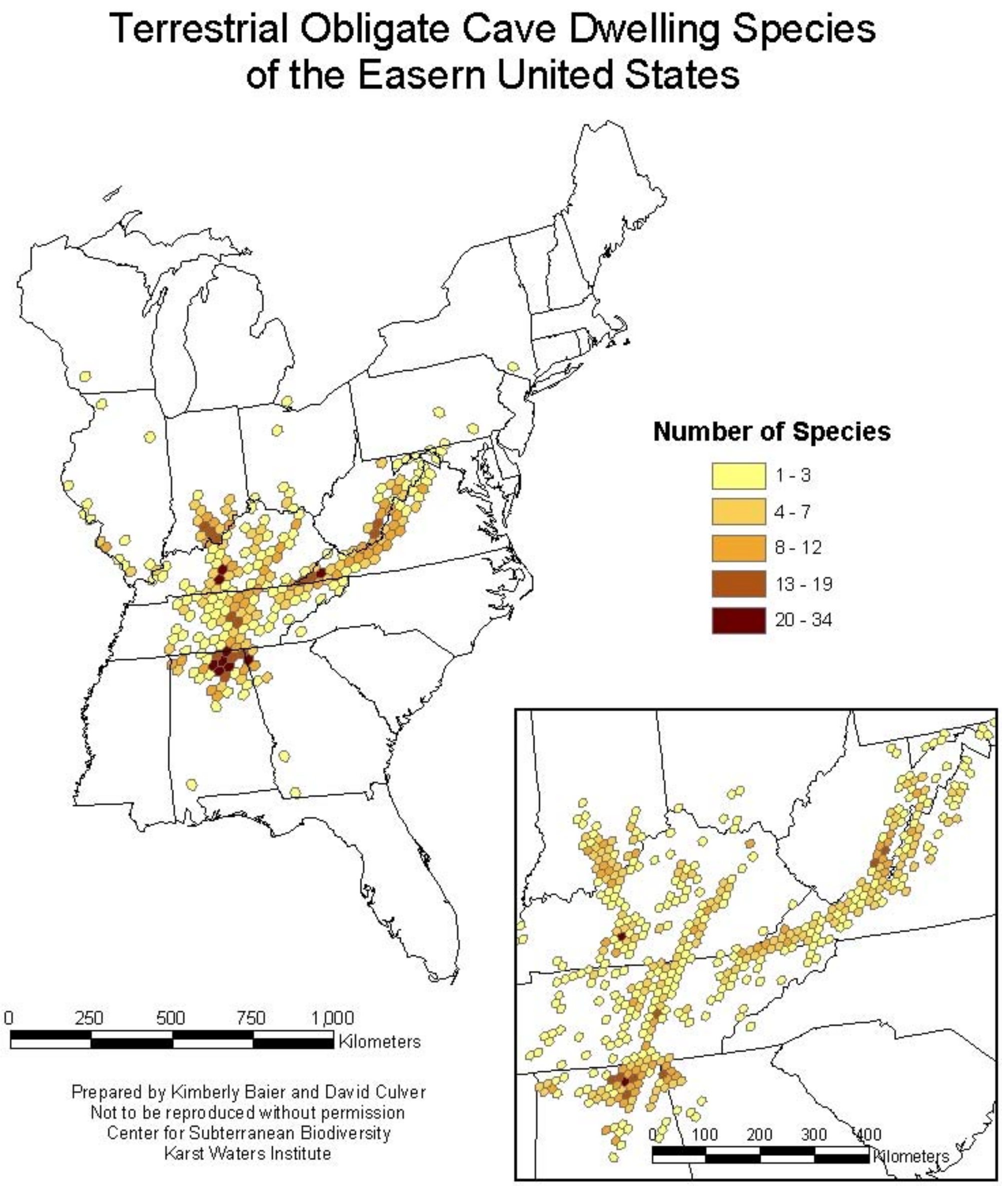
Invertebrates associated use of caves by the Allegheny woodrat

Allegheny woodrat (*Neotoma magister*) is a known visitor to cave entrance areas and, in some cases, far into the passages and caverns of the MACA cave system. Woodrats bring leaf litter and other materials into caves for nesting, cache diverse food stuff (seeds, juniper twigs, etc.) in caves, and establish "latrine areas" within frequently-visited caves. While woodrat fecal latrines are much less frequent than cave cricket guano deposits they have a high initial energy content and so can support diverse communities of subsurface invertebrates (Poulson 1992). Predatory staphylinid beetles (*Quedius* spp.) can greatly reduce numbers of *Ptomaphagus* beetles that feed on fungus growing on the feces. This predator-prey interaction alters *Ptomaphagus* competitive interactions with *Bradysia* fly larvae and can also affect fungal succession by affecting numbers of fungal competitors and/or fungivores (Poulson 1992). Finally, the substrate on which fecal latrines are deposited can, due to their effect on moisture levels within the latrine, alter the nature of their associated invertebrate community (Poulson 1992).

Invertebrate communities associated with leaf and wood fragments in caves

Varied amounts of leaf litter, sticks, and wood fragments (both natural and anthropogenic in origin) find their way into caves. The location of leaf litter and wood fragment deposits affects their energy content and so affects the diversity of subsurface invertebrates associated with them. Fresh, seasonally renewed litter just inside cave entrances supports both surface and subsurface species (e.g., the collembolan *Sinella* and the beetle *Pseudanophthalmus*, respectively) and so has a high species diversity. Further, seasonally renewed litter exhibits many stages of

Figure 6. Diversity of troglobites in the southeast. Note the high diversity in the Mammoth Cave region.



succession in one spot and can be mixed with cave cricket guano (Poulson 1992). Infrequently renewed litter located far from cave entrances is transported through vertical shafts and/or backflooding. This litter supports subsurface invertebrate communities of intermediate diversity (e.g., the snail *Carychium* and the millipede *Scoterpes*) because there is some succession and it is mixed with fine particulate organic matter from backflooding (Poulson 1992). Old, rarely renewed litter and wood fragment communities are similar because their food base is leached and shows no succession. The subsurface invertebrate communities associated with these deposits are depauperate (Poulson 1992). However, some of the rarest troglobites in MACA are found in these areas (e.g., *Pseudanophthalmus inexpectatus*, a beetle candidate for the endangered species list, and troglobitic harvestman *Phalangodes armata*).

Invertebrate communities associated with seasonally and perennially-wet habitats

Subsurface aquatic habitats can be distinguished ecologically by their reliability of permanent water, food quality and quantity, and presence/absence of predatory organisms (Poulson 1992). Generally, habitats with permanent water tend to be deeper inside the cave and so their food supply decreases. Thus, the number of stygobites in subsurface aquatic invertebrate communities increases with this gradient because their low metabolic rate and long life enables them to survive under these rigorous conditions.

Food is relatively abundant in seasonally wet "cave terrestrial" habitats, which include rimstone pools and travertine and terminal breakdown areas, due to their proximity to cave entrances. In these ephemeral habitats, food is deposited by percolation and flow from surface water (e.g., litter, bacteria, rotifers, protozoa) and deposited by cave crickets (i.e., guano). However, few invertebrates can survive the seasonal drying (exceptions include the amphipod *Stygobromus* and the flatworm *Sphalloplana*, both of which may aestivate), and so these habitats are depauperate.

Shallow stream invertebrate communities are relatively speciose due to their permanent water, even though energy input is sporadic and seasonal (i.e., litter associated with seasonal backflooding). The presence/absence of stygobites in shallow streams depends on the amount of allochthonous organic matter available. For example, if the food supply is low the isopod *Caecidotea* is the dominant species mixed with the amphipod *Stygobromus* and the flatworm *Sphalloplana* but with high food supply, the isopod *Caecidotea* is replaced by the amphipod *Crangonyx* (Poulson 1992).

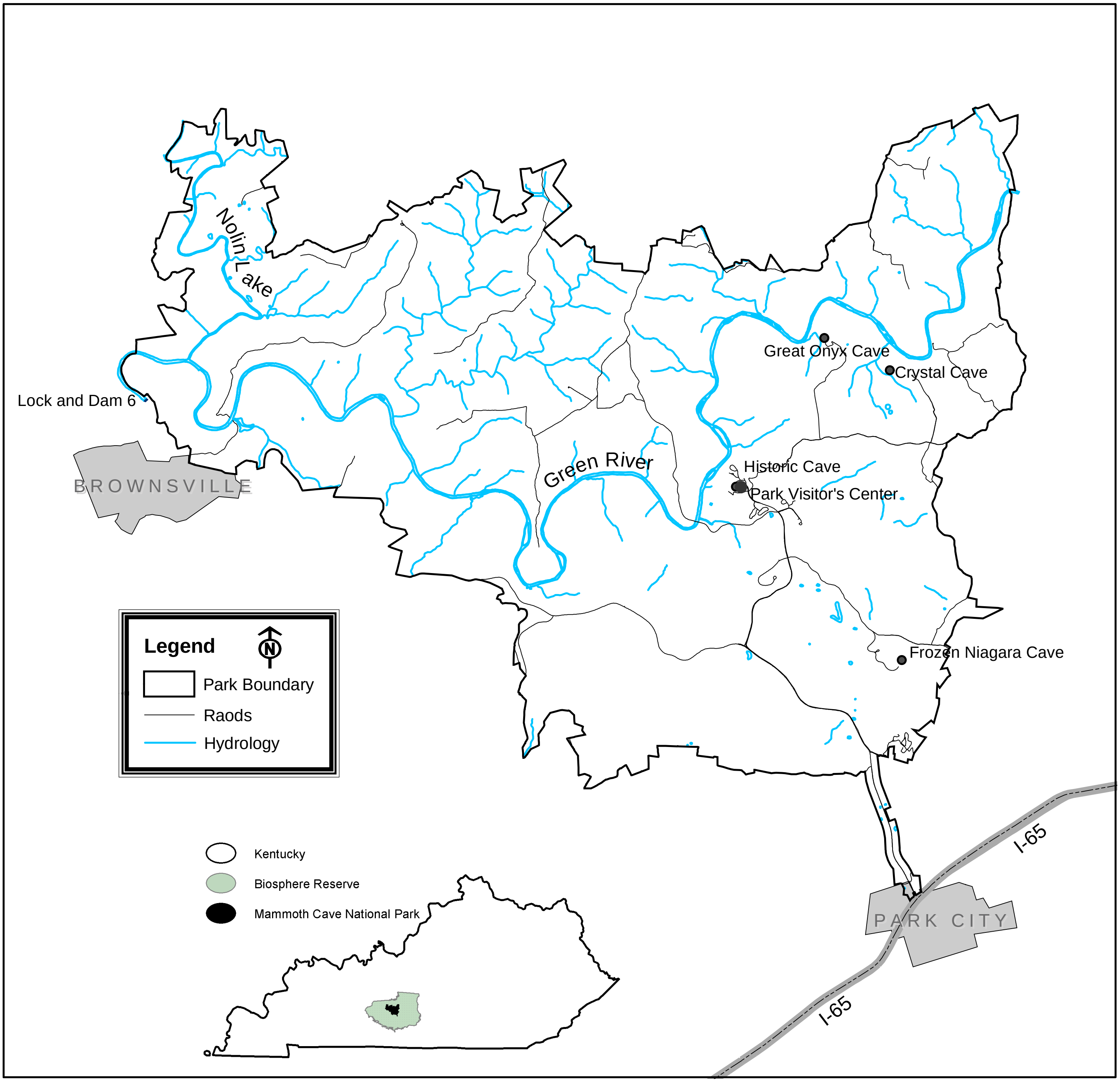
Medium-deep and Base-level streams (i.e., "cave rivers") support relatively un-speciose stygobite communities of fishes, crawfish, shrimp, isopods and amphipods. Differences in stygobite communities among medium-deep and base level streams may be explained by substrate complexity, among and within year fluctuation in water level, and the amount and frequency of renewal of fine particulate organic matter (Poulson 1992). Further, if located near vertical shafts with regular input from the surface, these communities can also have a significant troglobitic component. However, these habitats typically have larger stygobitic predatory species (e.g., the crayfish *Orconectes* and the fish *Amblyopsis*) along with smaller stygobitic prey species (e.g. amphipods and isopods). A significant park resource issue is generated by the fact that base level streams support populations of the federally listed endangered cave shrimp *Palaemonias ganteri*.

Anthropogenic stressors affecting cave ecosystems

The cave ecosystems of Mammoth Cave National Park are widely, and in some cases, severely impacted by both historic and recent human activities. Historically, cave entrances have been walled-off, cave floors and passages altered, new entrances added, natural entrances closed, and heat and light introduced into the pre-historically dark and cool cave environment. More recently, renovations and alterations to cave entrance structures, new lighting systems, diverse in-cave structural modifications, and use of some caves by organized tours, have contributed to further disruption of the cave ecosystem in some of the park's many caves. Cave entrance structures and modifications, cave lighting, in-cave structures, and tour/visitor usage of caves all modify air quality and air-flux patterns within caves. Changes in air quality and flux have diverse impacts across the cave ecosystem (Carson, 2001). Changed temperature and relative humidity adversely impact bats and invertebrates alike, by creating unfavorable or even lethal environmental changes. Salient among these are known and presumed impacts to historic bat hibernacula, resulting in many such areas in some caves becoming unsuited for use by Federally-listed bat species. Other significant threats and stressors to the cave ecosystem include water-flow/back-flooding into cave springs by the presently-impounded Green River, and chemical contamination of the cave ecosystem by pollutants transported in via seep and run-off water and into caves from sinking streams and other surface-water inputs (Helf, 2001). Pollution from diverse water- and adjacent-land-use-related sources and routes may be strongly deleterious within the narrow ecosystems found in caves. Cave entrance modifications also alter access routes and opportunities for trogloxenes to enter and exit caves. Such interference may impact not only directly-affected species, but also nutrient-input into dependent communities within the cave, with possibly significant ecosystem-altering effects (Linzey 1990). In addition to air- and water-quality-associated impacts, and impacts from direct management activities (i.e., cave lighting and entrance structures), special hazards to unique cave aquatic species, such as Federally-listed shrimp, may be posed by exotic fish stocked into the Green River to support local sport fishing. Stressors affecting the cave ecosystem are depicted in the General Cave Ecosystem Effects Model (Figure 10).

2. Mammoth Cave National Park's Green River-based aquatic ecosystem and some major stressors

Mammoth Cave National Park includes a range of "aquatic" habitats and environments. The most physically significant, and, for both management and issues- and resource-diversity reasons, important aquatic resources are those associated with the park's reach of the Green and Nolin Rivers. The park's reach of the Green is approximately 26 miles in length, and traverses the park flowing in a West-south-westerly direction. The park's reach of the Nolin is approximately 7 miles in length, and joins the Green in a confluence approximately 1.2 miles East of the Lock & Dam # 6, located adjacent to the parks West boundary (Figure 7).



Nolin Lake
Green River
Lock and Dam 6
BROWNSVILLE
Great Onyx Cave
Crystal Cave
Historic Cave
Park Visitor's Center
Frozen Niagara Cave
PARK CITY
I-65
I-65
Legend
N
Park Boundary
Raods
Hydrology
Kentucky
Biosphere Reserve
Mammoth Cave National Park

The Green, and, to a lesser extent, the Nolin, are host to significant faunal diversity, including approximately 53 species of fresh-water mussels, and over 80 species of native fishes. In addition to fishes and mussels, the park's reach of the Green supports a diverse benthic macro-invertebrate (BMI) fauna. Fishes, mussels, and BMIs have been identified as important resources for monitoring within the MACA LTEM Program. The General Aquatic Ecosystem Effects model is presented in Figure 11.

Non-mussel aquatic macro-invertebrates

There are three major habitats for surface aquatic invertebrates on Mammoth Cave National Park: Upland ephemeral ponds, Sloan's crossing pond, and the Green River. An inventory is underway of odonate species in all three habitats and is yielding new MACA and county records. Aquatic invertebrates living in the gravels and sands of swift water shoals of the Green River have an important role in the MACA ecosystem. There are approximately 200 invertebrate species (exclusive of mussels) known from the Green River within Mammoth Cave National Park (Schuster et al 1996), and many of these populations are severely impacted by the Lock and Dam #6 impoundment. Species richness, diversity, distributions and proportions of functional feeding groups were affected by the change from fast to slow flow associated with the dam. One major secondary driver for these changes is the high degree of siltation in the slack water reaches of the impounded zone. Bioassessment of Green River via many indices and metrics have all shown similar results. Water quality progressively declines from "good" to "fair" or "poor" in the free flowing, transition, and impounded zone respectively, according to the Ohio Invertebrate Community Index, which combines the results of many other indices (Schuster et al 1996).

Fresh-water mussels in the Green River

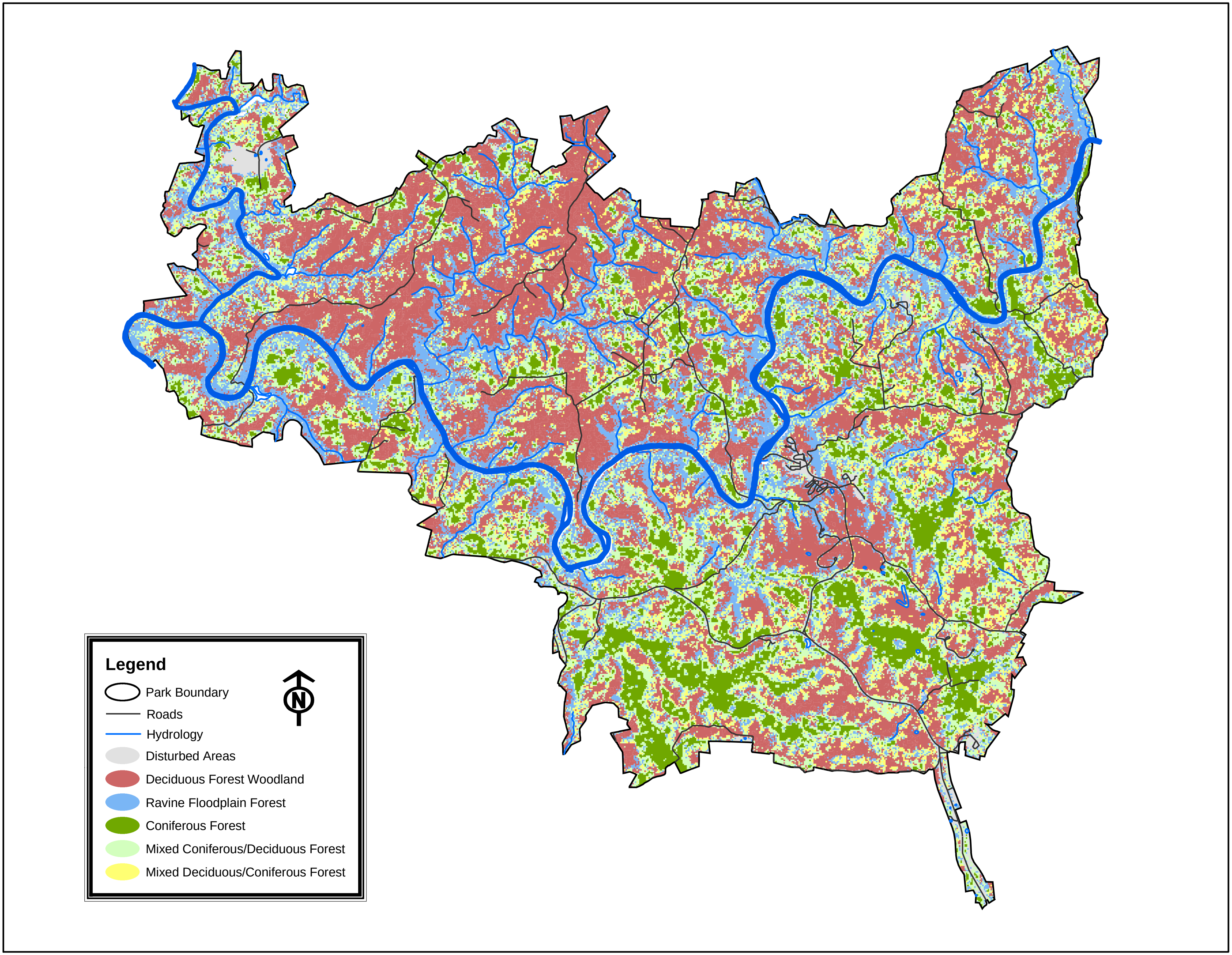
Approximately 35% of North America's mussel fauna are known from Kentucky, making it the third most diverse assemblage in North America (Cicerello et al. 1991). Nearly half of Kentucky's mussel species are found within the Upper Green River Drainage, which includes Mammoth Cave National Park (Cicerello et al. 1991). MACA's reach of the Green River is inhabited by six mussel species federally listed as endangered (i.e., *Obovaria retusa, Pleurobema plenum, Pleurobema clava, Epioblasma torulosa biloba, Cyprogenia stegaria,* and *Hemistena lata*), seven species that are candidates for listing by the USFWS, and seven species that have been assigned a conservation status by the Kentucky State Nature Preserve Commission. Thus, nearly half the mussel species inhabiting the Green River are considered rare, threatened or endangered at the state and/or federal level. For rarer species, the populations in the Green River are the best remaining occurrences [i.e., fanshell (*Cyprogenia stegaria*) and ring pink (*Obovaria retusa*)]. In fact, the Green River may contain one of the last remaining populations of *O. retusa* in the world. The Endangered Species Act mandates that MACA managers take actions to prevent extinction and enable recovery of federally listed mussels. Additionally, MACA's enabling legislation states that the park boundaries were situated to include significant sections of the Green River and to protect the river's integrity and its associated fauna. Over the past decade managers at MACA have invested a significant amount of funding to research, survey, and monitor the mussel species inhabiting the Green River. The restoration and protection from extinction of six federally listed mussel species via population augmentation is one of the top natural resource management priorities of MACA's Superintendent. A significant effort is now underway with the development of a mussel-rearing facility on the park. The presence of Federally-listed mussel species, plus the implementation of this rearing facility, have made mussel monitoring a priority issue for the MACA LTEM Program.

Some major anthropogenic stressors affecting the Green River ecosystem

MACA's reach of the Green River is significantly impacted by several local and regional threats. The most significant "local" threat to the park's reach of the Green is the historic impoundment caused by the Lock & Dam # 6. This impoundment, dating from ca 1906, has significantly altered flow regimes in the Green, resulting in formation of a large "impoundment zone". The impoundment zone reduces water flow, increases silt-deposition, potentially traps toxin-laden sediments, and may alter water temperature, dissolved-Oxygen, and turbidity profiles- significant components of aquatic habitats that may strongly impact many species. Other significant threats to the park's reach of the Green River come from the myriad impacts to river water-quality that are created by adjacent-land-use and associated run-off-borne contaminants. These include agricultural herbi- and pesticides, fertilizers, residential and feed-operation sewage and waste, industrial wastes, urban run-off, and chemical contamination from railroad and highway spills. Additional potential impacts to water-quality come from acid-deposition, metals-precipitation, and soot precipitated onto the adjacent land surfaces and transported into the Green via rain run-off and field drainage. Upstream activities have a large potential to alter both water quality and flow regimes in the park's reach of the Green River. These include the recently-initiated changes in flow-release regimes instituted at the Green River Dam, approximately 100 miles upstream of the park, and the on-going modifications to use of river-adjacent lands associated with the Conservation Reserve Enhancement Program being implemented upstream of the park. Other issues include impacts to native fishes from stocking of exotic sport fish, and possible impacts from muskrats acting as predators on local mussel populations. Introduced sport fish (trout) and impoundment effects in the Green River may also adversely affect the cave river aquatic ecosystem, by acting as an opportunistic invasive predator on cave shrimp, and causing changes in hydraulic-damming and back-flow into cave springs, respectively. Stressors are identified on the General Aquatic Ecosystem Effects model (Figure 11).

3. Mammoth Cave National Park's terrestrial ecosystem, its major natural resources, and the major threats to these resources

Mammoth Cave National Park is located within the Shawnee Hills section of the Interior Low Plateau Physiographic Province in southern west-central Kentucky. At present, MACA's surface landscape and ecosystem is a diversely forested one (Figure 8). Pre-park status land use included small (10-150 acre) farms of corn, hay, and tobacco on all the level land along the floodplain, in the valleys and on the uplands. The remaining forested slopes were used for pasture by pigs and cows and also selectively cut. South of the Green River, the limestone valleys and broad flat ridge tops provided better farming options than the sandstone dominated north side of the Green River.



Legend
Park Boundary
Roads
Hydrology
Disturbed Areas
Deciduous Forest Woodland
Ravine Floodplain Forest
Coniferous Forest
Mixed Coniferous/Deciduous Forest
Mixed Deciduous/Coniferous Forest
N

Parent material combined with variations in aspect, slope, elevation and soil moisture add much to the plant diversity of MACA. Limestone ridges capped with sandstone and alternately layered with embedded sandstone and shale create various soil conditions supporting a range of hydrologic regimes, pH levels and nutrient availability.

Lucy Braun (1950) classified the park as part of the Western Mesophytic Forest that includes Mixed Mesophytic Forest on mesic slopes and Oak-Hickory Forest on ravine flats. Important species on mesic slopes include *Fagus grandifolia* (American beech), *Liriodendron tulipifera* (tulip poplar), and *Acer sacharrum* (sugar maple) as well as 15 additional canopy species. Many of the park's environments, including upland flats and a range of xerix habitats, are diversely dominated by oak (*Quercus*) species. These tree associations correspond with diverse soils and underlayments. Where trees are sparse and soils are shallow, either naturally or through erosion and slumping, glade species occur.

Braun recognized mesic lower slopes as having a uniquely rich herbaceous layer due to the colluvial influence of the limestone substrate. Even in areas with obvious sandstone outcrops, the influence of the limestone parent material in combination with moisture level and aspect provides a habitat for vernal understory herbs such as trillium, toothwort, troutlily, woodland poppy, Solomon's seal, bloodroot, wild ginger, twinleaf, and Virginia bluebell.

The floodplain forest was defined by Ellsworth (1936) as a river birch- sycamore forest association, with some sycamores reaching 100 feet tall with 6 foot diameters (Ellsworth 1936). Illustrative of the changing composition of MACA's forests, Badger (1997) considered the floodplain forest to be a tulip-poplar-mixed maple association, with some species confined to the banks of the Green River. Badger also noted the invasive tree *Ailanthus altissima* along the Nolin and Green Rivers. Vernal herbs are limited along the floodplain because of silt deposits from winter flooding of the river. However, the invasive biennial *Alliaria officinalis* (garlic mustard) as well as *Glecoma hederaceae* (gill-over-the-ground) are common.

Cobblebars along the Green River, upland ponds and swamp forests are examples of wetlands within the park. Although these areas constitute a very small percentage of the parks total acreage, they add to the overall species diversity at MACA. Upland ponds such as Sloan's Pond support the rare sedge *Carex decomposita* as well as diverse grasses and sedges.

Hemlock-tulip poplar-beech is a very small component of the northern portions of the MACA forest, yet it contributes considerably to the diversity of the overall vegetation of the park. While there are pure stands of *Tsuga canadensis*, common associates include species more characteristic of the Appalachian and Mixed Mesophytic forest, including *Betula, Ilex*, *Magnolia* and *tripetala sp.,* and, in the understory, *Kalmia latifolia* and several species of *Vaccinium* are present. This association is limited by physiographic and moisture conditions to the upsteam ends of sandstone coves and is considered a rare and disjunct community this far west in the state. Faller and Jackson (1975) and Badger (1997) both considered the non-native invasive tree *Ailanthus altissima* a threat to eastern hemlock groves back in 1975 and 1997 respectively.

Despite the history of fire suppression and the ensuing encroachment of woody species, remnants of native warm-season grasslands supporting *Sorghastrum nutans, Andropogon ssp.,* and

Schizacharium scoparium, as well as many species of *Panicum* and *Dicanthelium* still occur within Mammoth Cave National Park. Open roadsides provide a refuge for forbs indicative of this community type, especially along Flint Ridge Road and Cedar Church Hill Road. Great Onyx Meadow and Wondering Woods represent larger and more diverse remnants of the barrens habitat of Kentucky.

The forest-dominated terrestrial ecosystem is noted for its vegetational diversity and complexity. This ecosystem supports a large diversity of resident and migratory bird species, the full range of large and small mammals indigenous to the region, and diverse reptile and amphibian fauna, though these latter groups are less-well described for the park than are the park's plant associations. Notable animal resources include a rich odonate (dragon- and damsel-flies) fauna, associated with upland ponds, several amphibian species of interest (wood frogs and spade-foot toads), woodrats (mostly in association with cliff-lines and cave entrances), and large populations of wild turkey and deer. While little is known regarding MACA's surface invertebrate community, it is assumed to represent a typical southeast assemblage. However, MACA is also assumed to act as a refuge for locally rare or endangered species in Kentucky. This may be particularly true for surface species in local counties (i.e., Edmonson, Barren, and Hart) considered rare or endangered by the Kentucky State Nature Preserves Commission; these species include two odonates (*Celithemis verna* and *Stylurus notatus*) and a geometrid moth (*Lytrosis permagnaria*). The forest ecosystem provides complex habitat and food resources for many animals of interest to park management, including several rare bat species, and provides the bulk of food resources for cave crickets- the key nutrient-conduit species that supports the cave terrestrial ecosystem. A General Terrestrial Ecosystem Effects model is presented in Figure 12.

Anthropogenic stressors affecting the terrestrial ecosystem

MACA's terrestrial ecosystem is subject to and impacted by many important stressors. Major stressors include (but are not limited to) air pollution-related gases and particulate deposition (acid-deposition, mercury-deposition, and elevated Ozone) affecting plants on the park, habitat-fragmentation effects on plant and animal species, affects on native plant and animal populations from introduced and invasive exotic species, poaching and other visitor impacts on species of interest, and effects associated with changing patterns in adjacent-land use. The effects of these diverse threats are, themselves, diverse and significant, both to species and biological communities, and to processes, such as ecological succession, occurring within the ecosystem [Threats and stressors are depicted in the General Ecosystem Effects models (Figures 10, 11, and 12) and General "Surface Factors" model (Figure 13)].

Table 2. Most significant natural resources of Mammoth Cave National Park.

MOST SIGNIFICANT NATURAL RESOURCES	
Caves (& formations)	Nolin River
Green River	Wetlands
Cave streams	T&E Species 7 ESA listed mussels Indiana and gray bats Bald Eagle Kentucky Cave Shrimp Crystal darter fish Eggert's sunflower Dragonfly
"Big Woods" (300 Acres of old growth)	
Plant species diversity (over 1,300 species of flowering plants including 84 species of trees.)	
Green River species diversity (80 fish, 170 macro invertebrates, 51 mussels)	
Unique habitats (glades, bogs, river islands, sinkholes, hemlock hollows, barren remnants, upland swamps, sandstone/limestone clifflines, and cave entrance ecotones, etc.)	

PART 1. PROGRAM DEVELOPMENT

A. Philosophical Basis and Program Development

1. Overall goals and philosophical approach of the program

The goals of the MACA LTEM Program are to detect, predict, and understand changes in major resources of primary interest to the park. The focus and orientation is on understanding and detecting trends in the park's three ecosystems through multiple-parameter monitoring of functional pathways that serve as conduits or connections between and among those systems. The program emphasizes ecosystem-based and issue-oriented monitoring. Ecosystem-based monitoring focuses on tracking resources within an ecological and ecosystem-context. This approach builds from identifying functional connections among "adjacent" resources within the ecosystem, so that monitoring multiple resources can provide complex and function-oriented understanding of processes, events, and patterns seen within the ecosystem. Issues-orientation focuses on the relevance of monitoring to meet the needs and goals of management actions directed at sustaining the quality or integrity of the parks ecosystems and reducing or eliminating threats from natural or human causes. Problems may be predicted when particular measures of change exceed acceptable bounds (defined by natural or historic limits and/or standards set by policy guidelines). Careful monitoring design and choice of ecological components and "indicators" are crucial in detecting meaningful levels of change and for providing timely, high-quality, reliable information to management.

Goals of Mammoth Cave Prototype LTEM Program
ecosystems
Provide early warning of abnormal changes in conditions of selected resources
Provide data to better understand the dynamic nature and function of park ecosystems
Provide data to meet legal mandates related to natural resource protection and visitor enjoyment
Provide science-based information to support the park resource management decision-making process
Understand the consequences of the park's management on the natural resources

a. The MACA program should emphasize monitoring of cave and karst resources

Our program should emphasize monitoring the cave and karst resources, and focus a strong effort on monitoring of the cave ecosystem, as the cave ecosystem is the historical central resource for the park, and a primary focus in its selection for status as a prototype park. This placement of emphasis on cave resources will best support our explicit responsibility for providing monitoring guidance and protocols to other cave and karst resource parks. This emphasis does not mean that non-cave-related resources (i.e., mussels) should not be addressed within LTEM, but, rather, that the LTEM Program should focus significant effort and resources on understanding the status and trends of the park's cave ecosystem.

b. The MACA LTEM Program should be a "Center of Excellence"

The MACA LTEM Program, should, emphatically, be a true "center of excellence". This will best be attained through focusing our program on the concept of doing fewer things better, in contrast to trying to do "zillions" of monitoring tasks, each with inadequate time and attention, and mediocre results. This goal calls for careful and conscientious limiting of our initial program size. Explicitly, it calls for programmatic adoption of a "lean and mean" approach to monitoring the enormous complexity offered by functioning ecosystems. (This was a major lesson learned from visits by MACA's prototype coordinator and the USGS-BRD scientist to Channel Islands, Prairie Cluster, and Cape Cod prototype monitoring parks in 2002.) It also calls for careful selection of monitoring questions and attributes. This would best be achieved through adopting a systematic focus and working with sets of functionally related and articulated attributes, rather than by selecting an incoherent and "scatter-shot" list of attributes that are not in some way connected with at least some of the other attributes being tracked. This focus also calls for careful attention to how monitoring and protocol development are done. The LTEM program should be based on SCIENCE and the tried-and-true ways of doing good science. Excellence in monitoring comes from careful attention to developing good monitoring questions, sound technique and design, and focus on conscientious performance of the complete monitoring task. Excellence in the program will also come from being "results-oriented", not "historically-" or "methods-" oriented. This will be best supported through a constant, careful review of what we have been doing and what we want to achieve. The GOAL of monitoring is to produce good, useful information to answer a status-and-trends question about the condition of a resource. The program should emphasize on-going and critical review of its monitoring questions, methods, and results. "If you are not getting good answers, don't keep doing the "same old thing"".

c. The MACA LTEM Program should use a function-based ecosystem approach

The MACA LTEM Program should use a functional approach to ecosystem monitoring, and, ideally, should strive to identify and focus upon the functional pathways that exist within and connect between the component ecosystems present at the park. Such a focus would support our mission and goal to provide sound, scientific information to best support informed decision-making by park management, and would also fully support our goal of truly systematically understanding some of the functions and dynamics of the park's ecosystems. Some other possible programmatic approaches, including that described in our initial program proposal (1993), appear to address a disjointed list of attributes in a non-systematic way. These approaches lead to detailed information about particular attributes, but provide little understanding of how those attributes relate to other attributes, to the larger ecosystem and to its function. This programmatic focus calls for us to develop our program from a coherent, functional ecosystem or pathway perspective, and for us to select monitoring attributes based, at least in large part, on assumed co-relativity, central functionality within pathways, and on their relevance to enhancing our understanding of the system.

2. Monitoring program limitations

Limitations of monitoring exist because of the inherent complexity of the MACA combined ecosystem being composed of at least three reasonably discrete functional ecosystems, plus dynamic interconnection pathways. Insufficient scientific knowledge and challenges in distinguishing natural (in-system) variability from human impact-related or caused variability add to the difficulty in clarifying monitoring issues and the development of appropriate monitoring objectives. Additional limitations are imposed by the finite nature of available monitoring resources (time, funding, technical expertise), both within the LTEM program, and within the larger context of MACA park funding and development. These limitations require that the MACA LTEM program develop and focus on a carefully selected set of ecosystem attributes- a set which will "best" address the highest- priority needs for the park and its resources. Selection will focus on identifying those monitoring attributes which can contribute robust and centrally-important insights into ecosystem function in the most efficient and efficacious ways.

A limited program can gain future utility and strength through incorporating means and flexibility to adapt and change as shifts in monitoring needs occur. Part of this adaptability will be provided through periodic review and assessment of current monitoring efforts and methods. Review will identify those efforts and methods that may have become redundant through revealed close correlation (i.e., initial monitoring tracks three potentially correlated measures. Review shows that all 3 are indeed closely correlated). Some closely correlated measures may then be dropped, freeing up monitoring effort that can be focused on new issues and questions. Additional flexibility will be gained through designing monitoring efforts to detect specific changes, and, when these changes have been detected, some appropriate management action may be recommended. Following this detection and action-recommendation, it may be appropriate to change, reduce, or delete this monitoring project, thereby releasing monitoring resources for use in other projects and to address new questions.

B. Conceptual Framework for Developing Monitoring Protocols

1. Overview of the ecosystem pathways and attributes identification and prioritization process

The core element in developing an ecological monitoring program is identification of appropriate ecosystem components to focus on. The challenge lies in "HOW" to select those components. A number of alternative "attribute ranking and prioritization" methods have been proposed and used in various prototype parks, as well as in the monitoring programs being built within the Vital Signs networks. To date, there has been little agreement, let alone real consensus, on how to best rank and prioritize monitoring attributes. Each offers a combination of "user-friendliness", efficiency, and precision in attribute selection. Each offers value as an effective tool to address the resource issues and meet the needs specific to its program. It is likely that no one "universal" or "perfect" identification process exists. MACA's program, like all others, exists within unique ecological circumstances, deals with special and diverse resources, and faces park-specific management needs and program challenges. Our "best" approach to meet the identification challenge is to combine good features from other programs and processes and create our own, "custom", MACA attributes identification process.

The MACA LTEM program focuses on meeting park resource management needs while monitoring within an ecological integrity context to provide useful indicators of ecosystem status and functional condition. The goal of the MACA attributes identification process is to produce a list of "highest priority" attributes that will be the subjects of the initial phase of monitoring protocol development and implementation. This list will be defensible, and will encompass our efforts to rationally determine which of the many possible attributes we will focus our monitoring effort on. Ideally, these highest-priority attributes will be those identified as being ecologically meaningful and systemically relevant to park resources and needs, suitable for supporting management needs and decisions, robust and revealing of trends within park systems, cost effective, and effective at addressing legal and policy mandates.

We have achieved this through development of a multi-step, conceptual models-based, hierarchical ecosystem components (attributes) ranking process. The MACA process uses formal selection criteria and a defined scoring system (Appendix D) to promote "objectivity" in process decision-making. The MACA process uses discrete steps that partition the work-load into manageable units. Process steps yield defined products that serve as baseline resources for subsequent process steps. Step products can be archived as a detailed record of process implementation, decision-making and lessons-learned. Implementation of the MACA process emphasizes teamwork, collaboration, and reaching informed consensus during decision-making steps. The MACA LTEM team, together with diverse "outside participants" (other park staff, NPS I & M network staff, subject-matter experts and professional scientists), collaborate to perform the several steps of the process. In the following process description, the phrase, "LTEM team" will refer to the MACA LTEM Program Coordinator and staff, along with the Chief and staff of the Division of Science and Resources Management (SRM) at MACA, and the USGS Ecologist assigned to assist and advise the MACA LTEM Program. "Lead team" will be used to denote the smaller "program management team" comprised of the LTEM Coordinator, the Chief of SRM, and the USGS Ecologist. This smaller group will coordinate the diverse efforts underlying the attributes identification process and will complete the process steps in Round Two.

The MACA process is based upon analysis of conceptual models that summarize the park's major ecosystems. An important, and unique component of our process is the development of simplified ecological "Habitat Pathways" models that summarize selected habitats and issues-of-importance seen within the larger ecosystem and models. Each Pathway captures a small set of "Key" and linked components (attributes) plus some of the drivers and stressors associated with those attributes (see example Pathway, Figure 9). These "Pathways" models are, primarily, work-load-partitioning devices that allow a decision-making team to focus on a relatively small and discrete part of an otherwise hugely complex task.

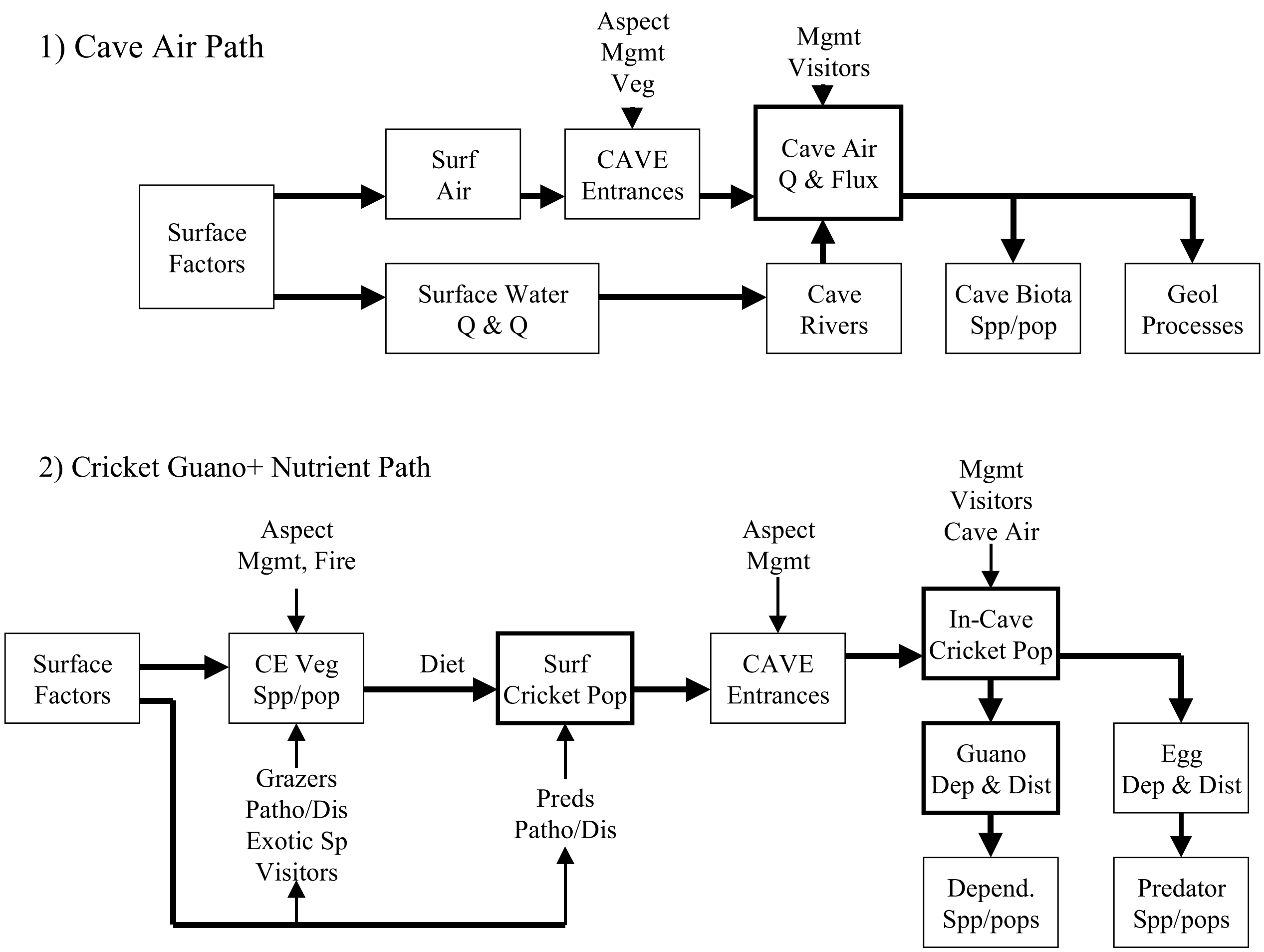
In overview, the MACA process begins with collection and review of information on the park's component ecosystems, identification of threats and stressors thought to be impacting park resources, and identification of management issues concerning status and trends in the condition of the park's resources. This review is followed by development of ecosystem conceptual models. From these, the LTEM team identifies several "Habitat Pathways", and simple descriptive models are developed for each pathway. Pathway models are then used as tools to support selection of a short-list "matrix" of "high-priority" attributes in a criteria-based, multi-step ranking process. The resulting "high-priority attributes" list (couched in the form of a "Pathways X Attributes" matrix) will direct selection of monitoring protocols for development and implementation in the initial implementation phase of the MACA LTEM Program.

a. "Early Steps and the Information Base for the MACA LTEM Plan"

The MACA LTEM Program (and its Conceptual Plan) is, first and foremost, a program intended to monitor ecological components in order to address questions about the status and trends in the park's ecosystem condition, where "ecological components" are roughly synonymous with "natural resources". Natural resources on national park lands are both a valuable legacy and a variably-threatened legacy. Ecological components, ecosystems, and natural resources are all subject to natural "drivers" (processes and interactions that act on and influence the condition of resources) and anthropogenic stressors (forces, interactions, and conditions created by Man which act on and influence the condition of resources). The NP Service is broadly and deeply interested in the status and trends in condition of the natural resources under its stewardship, and is rightly concerned with the stressors which impact those resources in diverse and severe ways.

These interests and concerns are expressed as issues and questions being raised by park unit management about the status of their resources and the impacts various stressors are having upon them.

Figure 9. Sample pathway models



The "ground-work" step in developing a monitoring program is to assemble information about the resources, relevant threats, and specific management needs and questions that provide the "*raison d'terre*" for the program's existence. For the MACA LTEM Program, this information was developed from several activities and "steps". Identification of important natural resources, identification of anthropogenic stressors thought to impact park resources, and information on park management issues, was assembled from multiple sources and through multiple venues. A well-developed summary identifying many park resources and the stressors acting upon them was provided by the 1993 Proposal. Additional resource identification, details on stressors, and information on management needs and issues were developed during three "scoping" meetings held in 2002. Two of these meetings, held on the park in May, 2002, provided significant resource, stressor, and management information of direct relevance to MACA. The first of these meetings was a “Vital Signs Scoping Meeting” held by the CUPN on the park (01 May 2002). MACA staff participated in and contributed to this meeting and to its development of information for use in the Network Vital Signs Monitoring Program. The second meeting (15 May 2002) was a MACA park-focused “Ecosystem Scoping” meeting, where MACA SRM and LTEM staff identified the park’s salient natural resources, stressors impacting these resources, and management issues and concerns about the status of resources on the park. Additional ecosystem and system-modeling information, along with detailed information on stressors and their impacts on resources, developed from a third meeting, held at Great Smoky Mountains National Park (GSRM) in August, 2002. The GRSM meeting was a combined-networks meeting to develop in-depth ecosystem models for the general aquatic and terrestrial ecosystems found in the CUPN and APHN networks. MACA staff participated in and contributed this meeting. Information obtained from this meeting included identification of diverse ecosystem components, details on types of stressors and natural drivers acting on aquatic and terrestrial ecosystems, and identification of many potential “Vital Sign Indicators” that could be tracked within one or another monitoring protocol. The information developed in these three meetings played a strong formative role in developing ecosystem models and identification of possible stressors acting on MACA’s 3 ecosystems. MACA’s major natural resources based on four categories are identified in Appendix A and listed in Table 2.

Development of information on MACA park management needs and monitoring questions followed a multi-step “process”: insight on pre-1993 management perspectives and issues was developed from the 1993 Proposal, which focused on cave and karst, and selected aquatic resources on the park. Additional information on park and CUPN management needs and issues developed from two the “Scoping” meetings held on the park in May, 2002. Appendix B presents a composite of MACA and CUPN natural resources, impacts, management resource issues, and management questions derived from the May meetings. Further MACA management-issues information developed through discussions with MACA management in mid-2002.

The final, and essential, step in developing the “management issues and questions” foundation for the MACA LTEM Program was completed with the “tasking” of MACA park management to produce a set of “top ten” management questions for address within the LTEM Program. MACA park management produced a set of ten major, natural resource-and-stressor-impact-related questions in early 2003. This list, presented in Table 3, puts forth the top ten questions that park management identifies as its immediate and near-future priority needs for address by the LTEM Program through data obtained from its monitoring projects. These “top ten” monitoring questions are a crucial component in developing the ranking criteria to be used in the MACA attributes identification process, described in the next section.

Diverse additional insight into cave resources and cave resource management issues developed from the Cave Ecosystem Workshop hosted by MACA in April, 2003. This workshop provided a forum for exchange of information on resource and management issues amongst cave specialists from several “cave resource” National Park Service units and state parks. Attendees included significant contributors to research and monitoring efforts in MACA’s cave ecosystem, along with several academic ecologists. Cave resource, stressor impact, and management issues information developed in this workshop contribute breadth and a diversity of perspectives to the information base used for developing the MACA LTEM Concept Plan.

Table 3. Most significant natural resource management issues of Mammoth Cave National Park.

MOST SIGNIFICANT RESOURCE MANAGEMENT QUESTIONS
1. How are Cave Water Quality and Quantity (Q & Q) changing over time, in respect to changes in surface water Q & Q, changes in dam release regimes, and CREP impacts?
2. How are Surface Water Q & Q (Green/Nolin Rivers) changing over time, in respect to Air Quality, Dam release regimes, and CREP impacts?
3. How is Adjacent Land Use changing over time?
4. How are Nutrient Inputs (flow, rate, distribution, composition) into the Cave Ecosystem changing over time?
5. How are Cave Air Quality and Flux changing over time, in respect to cave management and surface air quality?
6. How are Selected Plant Communities and populations changing over time, in respect to surface air quality, exotic species, grazing impacts, poaching, prescribed fire, and pests and disease?
7. How are Mussel Communities and populations changing over time, in respect to dam impoundment effects, changing release regimes, MACA's mussel propagation efforts, water quality changes, CREP impacts, and muskrat depredation?
8. How are Fish Communities changing over time, in respect to dam impoundment effects, changing release regimes, impacts via exotic species on cave fauna, CREP impacts, and reproductive-host relationships with mussel populations?
9. How is Vernal Pool Water Q & Q changing over time, in respect to surface air quality/acid deposition, heavy metal contamination, upland invertebrates and amphibians?
10. How are Cave River (Cave Shrimp, Fish, Crayfish) populations changing over time, in respect to changes in surface water Q & Q, invasion and depredation by surface aquatic species?

2. Ecosystem conceptual models--tools to support attributes and indicators identification

A concept-model-driven process requires a detailed step of conceptual model development and construction, as such models may help to depict and anticipate how a system will respond to external stresses (Noon, et al. 1999). Conceptual models that depict key structural components, functional connections and pathways, and key system drivers can assist us in thinking about the scope and context of the processes that may effect ecological integrity (Karr, 1991). And, perhaps essential to effective monitoring program design and development, models serve as strong, cross-disciplinary heuristic devices during program development (Allen and Hoekstra 1992). The MACA attributes identification process bases upon moderately detailed ecosystem concept models that depict system components and some functional connections, together with major natural drivers and anthropogenic stressors. Four general model formats have been developed. These four formats serve to summarize at different levels the park's ecosystems, partition our total system knowledge and functional concepts into smaller (hence more accessible for non-ecosystem experts) blocks, and serve as tools to support system discussion and analysis from multiple perspectives. The model formats include generalized "whole system effects models", reduced "pathway" and/or habitat-focused models, detailed attribute-focused models, and attribute-focused "pragmatic" models. The four types of conceptual models have several features in common: Each includes a set of ecosystem components (= attributes) depicted as labeled boxes and bubbles. The included attributes are either "major" abiotic environmental components, such as air quality, or biotic (taxonomic-based) system components, such as biological populations or communities on the park. All models depict generalized interactions between components with lines and arrows. These arrows do no not generally specify either the magnitude or actual type of interaction (i.e., predation impact), but, rather, serve to indicate that attribute "A" is thought to impact or influence in some way attribute(s) "B". Each model presents a set of attributes and putative "effects" connections subjectively chosen from among those discussed in the research and historical reviews available on park ecosystem issues and resources. All of the models are very simplified, and tell "less-than-the-whole-truth"- they are simple depictions and are intended as discussion guides, not as complete, quantitative depictions of some total knowledge base. As additional support tools, a set of "nutrient pathway" models were constructed to present portions of the park's three major ecosystems from a different perspective.

The generalized "effects" models broadly summarize "entire" ecosystems as a chain of events/ attributes/properties, where major system components (attributes) are placed in some functional ("effects" or process-connected) relationship to other components, and documented (or potential) "effects paths" are identified as links between adjacent components. Such models portray ecosystems as a series of "component "a" effects or impacts component(s) b" connections (the converse is implicit: component(s) "b" are impacted by and respond to component "a"), but do not attempt to depict either magnitude of effect nor specific effect details. A general "effects" model has been built for each of MACA's three major ecosystems (the cave ecosystem, the terrestrial surface ecosystem, and the aquatic ecosystem, based largely on the Green River within the park) (Figures 10, 11, and 12).

A set of eighteen "Habitat-focused Pathway" models have been developed to summarize seemingly important sub-sets of MACA's 3 ecosystems. The "Pathway" models serve to functionally isolate some apparent ecosystem or "habitat-associated" "pathway" or set of components-of-interest that occur within the system, and depict effects-pathways and interactions within that set. Each "Pathway" encompasses a set of ecological attributes arranged along some putative effects pathway. The attributes and connections are taken directly from the "parent" ecosystem concept models. The Pathway models share a common format, in that a large group of common stressors and drivers are summarized in a box labeled "Surface Factors" ["Surface Factors" are identified for reference in a separate model (see Figure 13)]. This summarization reduces the visual complexity of the model and acknowledges that most major threats are broadly common to the ecosystem. The Pathway models also identify some of the possible or likely opportunities park management has, through its actions, to impact an attribute or an interaction within the pathway. Pathway models assist the attributes identification team efforts through focusing attention on the discussion of interest and reducing confusion through deleting "distant" and/or less valuable component knowledge (see a sample Pathway in Figure 9).

Detailed "attribute-focused" models depict a more fully understood or defined attribute or pathway component in considerable detail, and thus "encapsulate" our deeper or broader knowledge of that attribute (see Figure 14, Cave Cricket Populations). This approach can facilitate recognition (and discussion) of what we do, and do not know, about the attribute of interest. Attribute-focused models will be developed for each monitoring protocol, as this model format encompasses the detailed understanding that contributes to refined monitoring questions, and are extremely useful in identifying (and predicting) system response to acute and chronic disturbance.

The "Pragmatic" models serve to identify and delineate "useful" knowledge about selected ecosystem attributes. Useful knowledge, in the monitoring context, may be measures or attribute-properties or response variables that could serve as "key" or primary ecological "Indicators" for monitoring (see Figure 15, Woodrats). "Pragmatic" models, like "Attribute-focused" models, are developed as support tools within the MACA attributes identification process, and will be further developed within specific monitoring protocols, as they identify useful monitoring indicators.

The "nutrient pathway" models are an alternative and conventional approach to modeling ecosystems, based upon viewing the system as a energy and matter pathway. Such models are useful for viewing potential links and fates of materials in an ecosystem (i.e., where does a metallic contaminant, such as Mercury, go within a system? How is it passed through the system and what will be effected by its passage?). Nutrient-pathway models have been developed for portions of MACA's three ecosystems, and serve as additional team discussion support and reference tools during process implementation. Ultimately, these models will be "fleshed-out" as detailed, quantitative research and monitoring data become available. They will, in time, become good functional depictions of how our ecosystems actually operate, in an energy flow and matter cycling, ecosystem context.

The conceptual models are heuristic tools intended to support the LTEM team in its efforts to identify salient interconnection pathways and select monitoring indicators within the MACA ecosystems. The models portray the systems as "box and arrow" flow-charts, and the team can readily envision or see potential pathways by inspection of the models. The team reviews the models, discusses the content, and can reach some consensus on their interest in any given pathway and attribute, and on its validity as a useful perspective on the ecosystem. The pathways identified from these general effects models are those which the LTEM team believes are of salient interest or importance- owing to their connectivity to ecosystem resources and/or relevance to park management questions and needs.

Figure 10. General Cave Ecosystem Effects Model

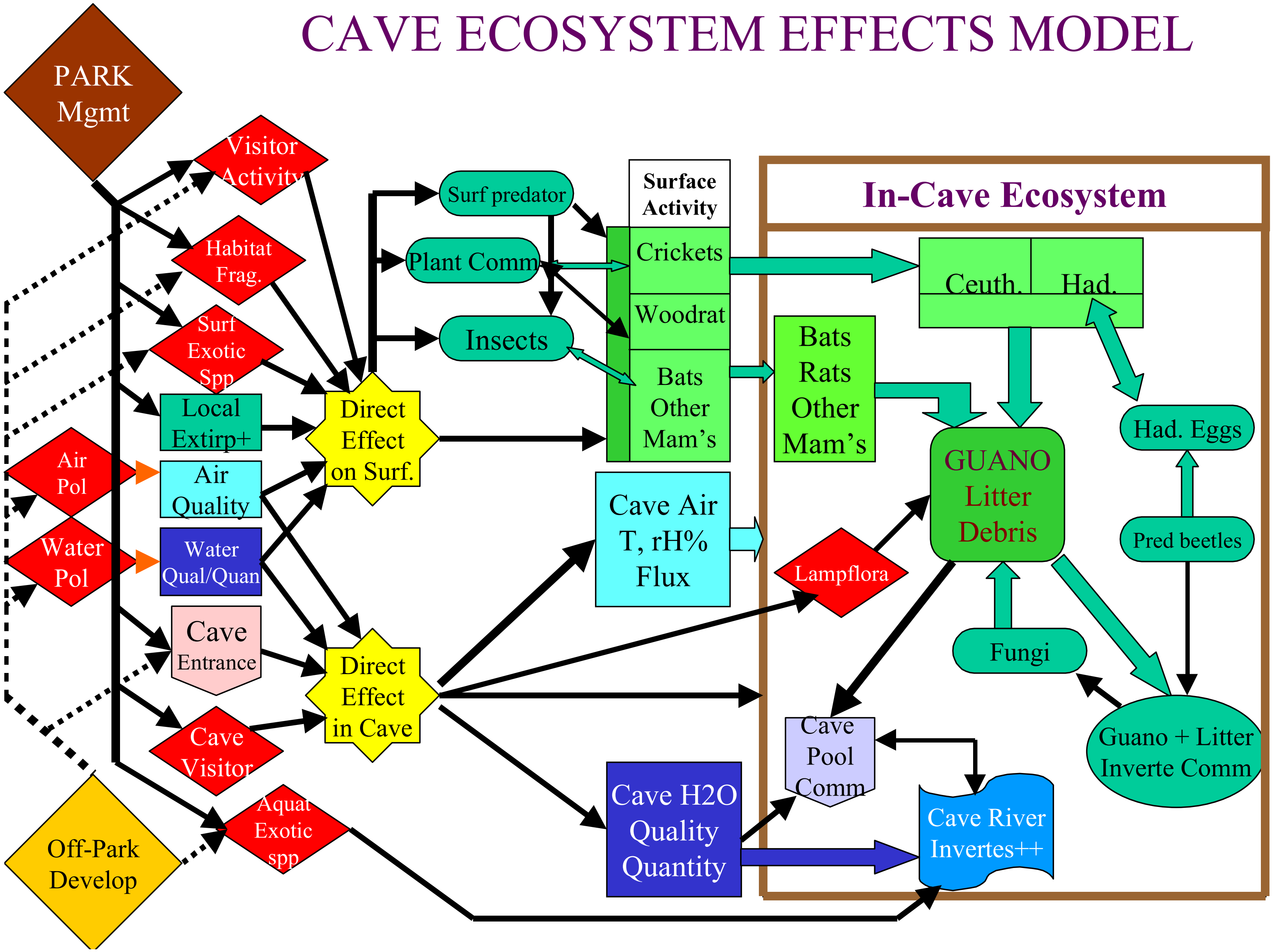


Figure 11. General Aquatic Ecosystem Effects Model

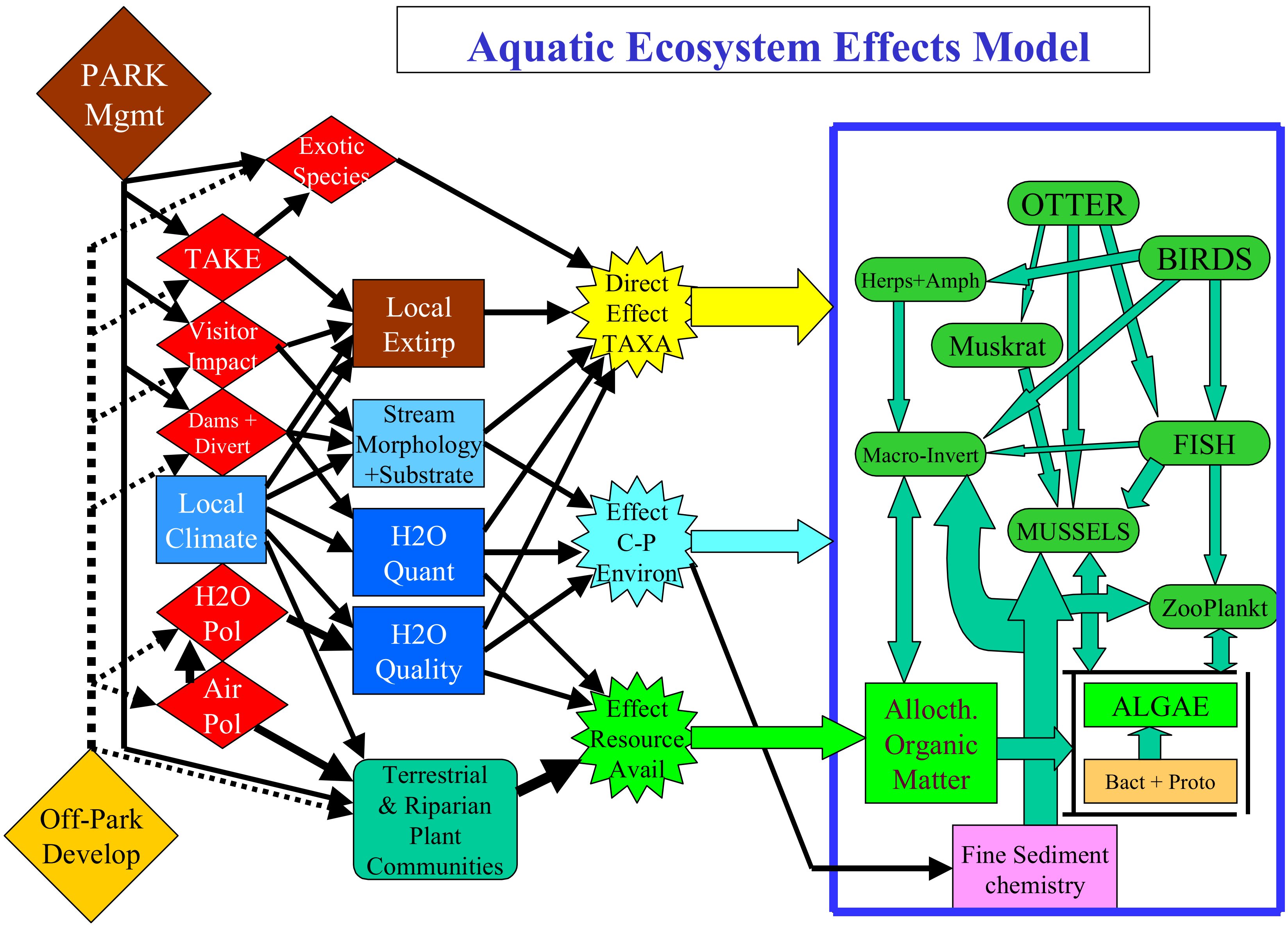


Figure 12. General Terrestrial Ecosystem Effects Model

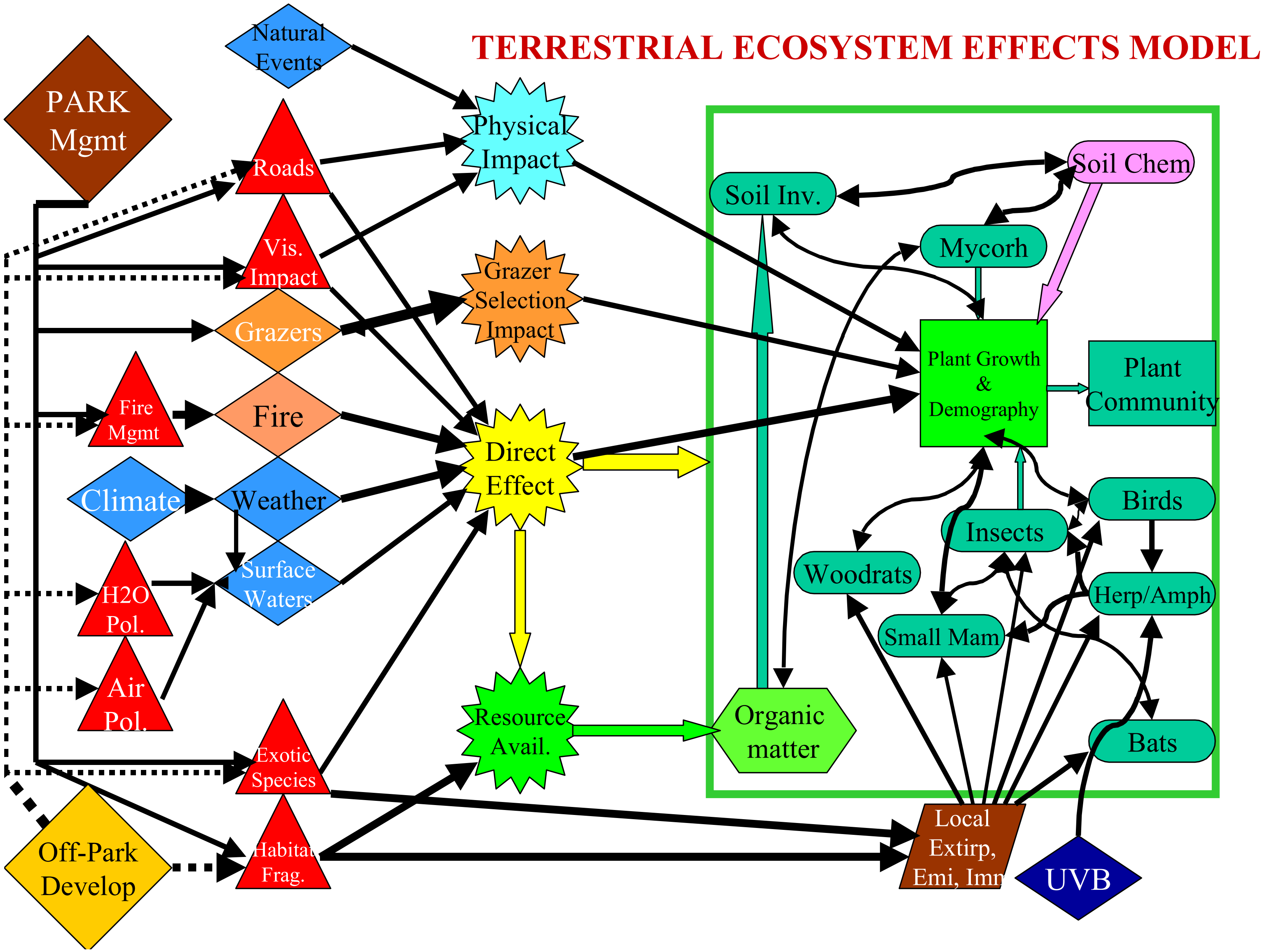
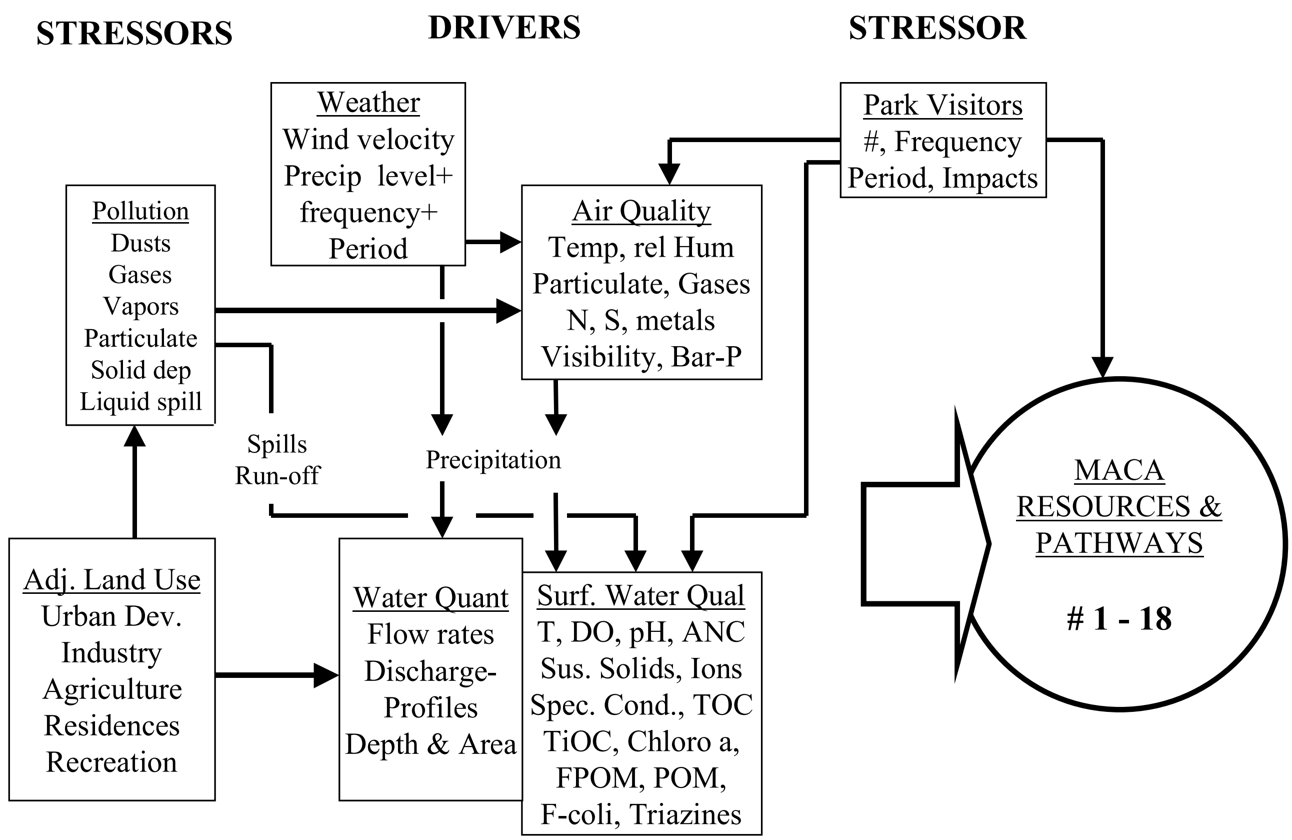


Figure 13. General "Surface Factors" Model and some Measures



The set of conceptual models will also serve as a diagrammatic and dynamic record of our current state-of-knowledge. Archived versions will be a primary record for the decision-making process leading to development of the monitoring program content and focus. Over time, as new information is accumulated, new models will be developed to incorporate this improved understanding. The resulting model series will provide a diverse and valuable record of how we change our concept of what our ecosystems are and how they function.

3. Steps in the MACA ecosystem attribute ranking and prioritization process

The identification and prioritization phase of the MACA process proceeded in a series of "rounds" and steps following the development of 18 "Pathways" models described above. "Round One" sorted the "Pathways" to select a smaller set (n=6**) to focus on, then ranked the attributes within each of these pathways (Note: 8 Pathways were initially identified for further ranking. After the initial selection, 3 Pathways- those concerning Bats, Woodrats, and Cave

Crickets, were combined into one functional “group Pathway”, Guano-Nutrient Import, as all share most attributes). After the attributes were ranked, the 6 pathways were ranked, resulting in a “raw Pathways X Attributes Matrix”. In “Round Two”, the “LTEM lead team” refined the raw matrix from Round One, and produced the final, reduced Pathways X Attributes that will determine the protocols to be developed for the program. The following paragraphs describe the several steps of the MACA process in detail, and should be read in conjunction with review of the process model (Figure 16), and review of the Ranking Criteria used in the process (Appendix D).

The first ranking step (Round 1, Step 1) compared among 18 pathways using two (2) “formal” ranking criteria (see Appendix D). Round 1, Step 1 yielded a pathway list which identified six (6) pathways to be our key focus for monitoring. The remaining ten pathways were placed “off-the-table”, as being of lesser importance. Their “less-important” status denotes that they are less central to park management needs, or that they may be less well understood (thus, candidates for further research before monitoring- see Process Outcomes description), in comparison to the 6 higher-ranked pathways. The pathways ranking step proceeded as a team-discussion process, with discussion focused upon reaching team consensus using the two (2) “formal ranking criteria”. This step involved two (2) “outsider” professional ecologists, who, together with the USGS Ecologist, provided technical advice and ecological content discussion from a non-MACA-centric perspective.

The second ranking step (Round 1, Step 2) considered those pathways that we ranked as being of most importance and/or interest (the top 6 from Round 1, Step 1) to the LTEM program. In this second step, the LTEM team delineated or Prioritized what attributes within each pathway would be the best focus for initial monitoring. The working assumption is that we probably can “paint” a reasonable pathway functional picture by simultaneously tracking a few linked “key components” within that pathway, rather than by having to monitor all identified components. Thus, this ranking step will consider which attribute(s) are better potential indicators of the pathway’s function and dynamics, and which can best be monitored, as limited by ecological relevance and monitoring efficacy. This step also asks whether monitoring of attribute “k” in pathway “x” may also supply a useful element in understanding pathway “y” (a selection for monitoring attributes that relate to multiple pathways = more bang for effort = robustness). Round 1, Step 2 also proceeded as a team-discussion process, and sought to develop ranking consensus through discussion focused around four (4) sets of ranking criteria. These criteria rank the Attributes with respect to their ecological significance within its pathway, its robustness or connections (“bridging”) to other pathways, its relevance to management decision-making, and its monitoring efficacy (see Appendix D). This step involved two (2) “outsider” professional ecologists, who, together with the USGS Ecologist, provided technical advice and ecological subject-matter expertise from a non-MACA-centric perspective. These experts assisted the LTEM team in selecting the "better" attributes for monitoring, and could contribute to the actual numerical scoring done at this step. Round 1, Step 2 yielded a set of attributes ranked within each of the 6 Pathways considered, in the form of a raw “Pathways X Attributes” table or matrix.

Figure 14. Cave cricket populations focus model

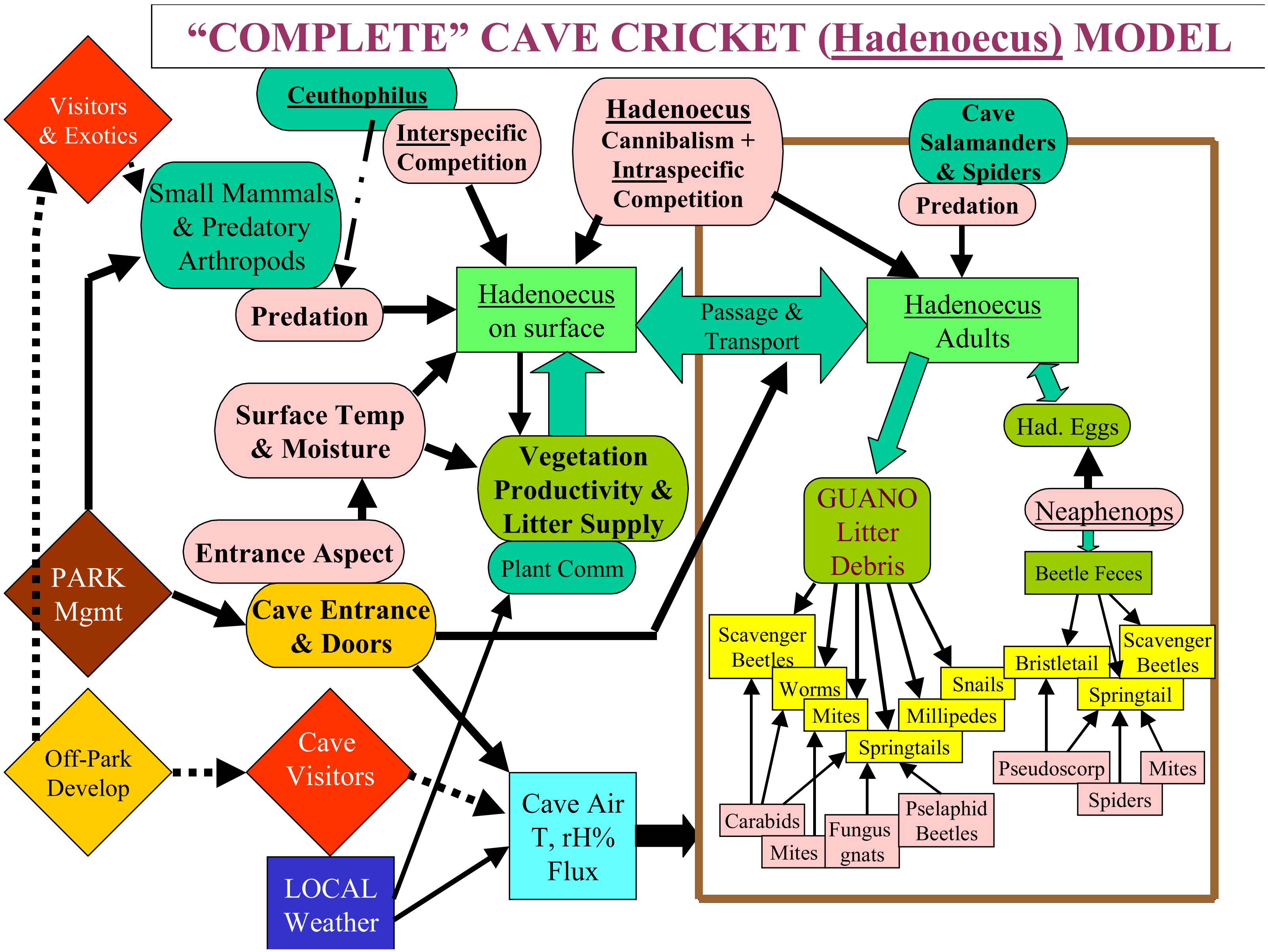
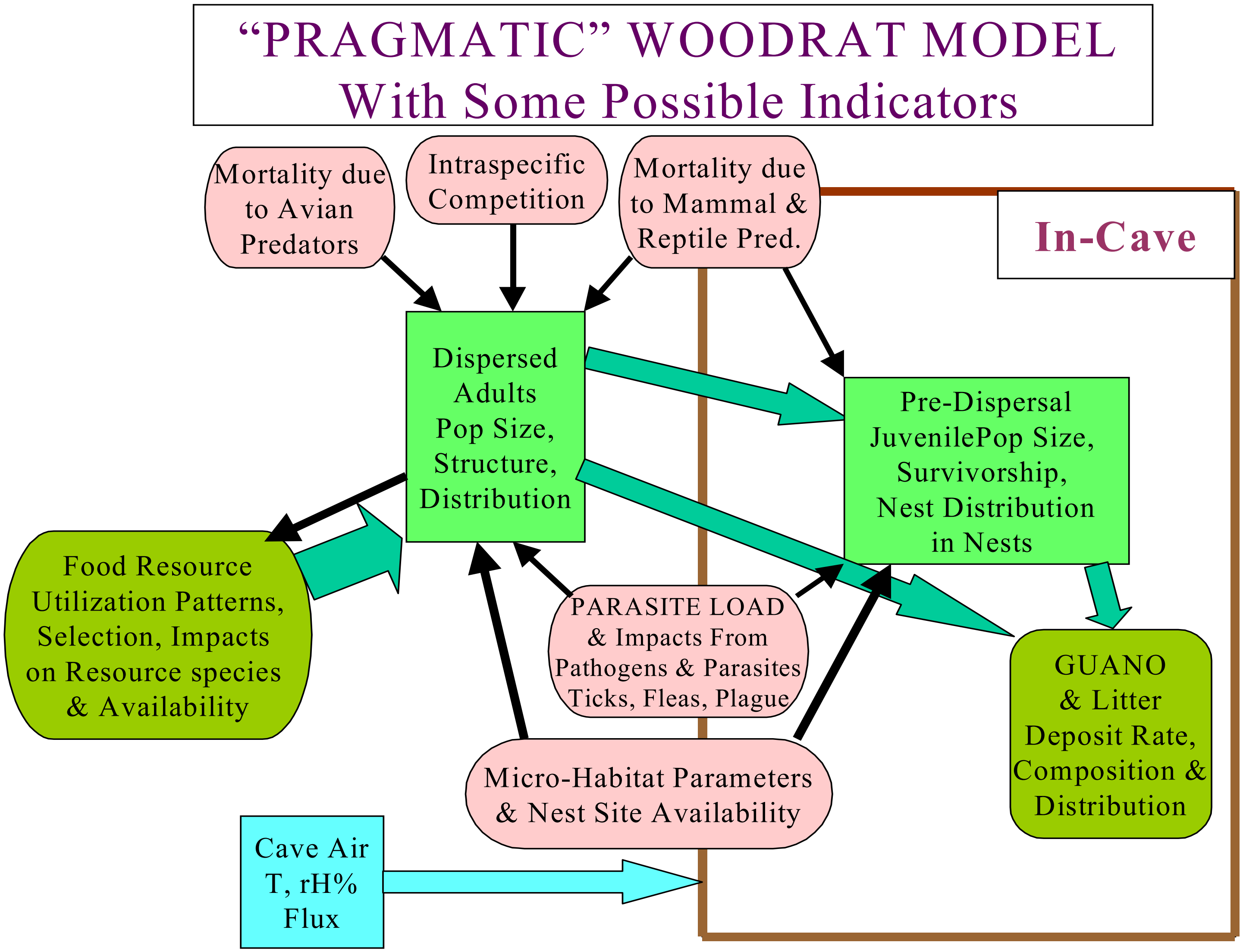


Figure 15. Pragmatic woodrat model with possible indicators.

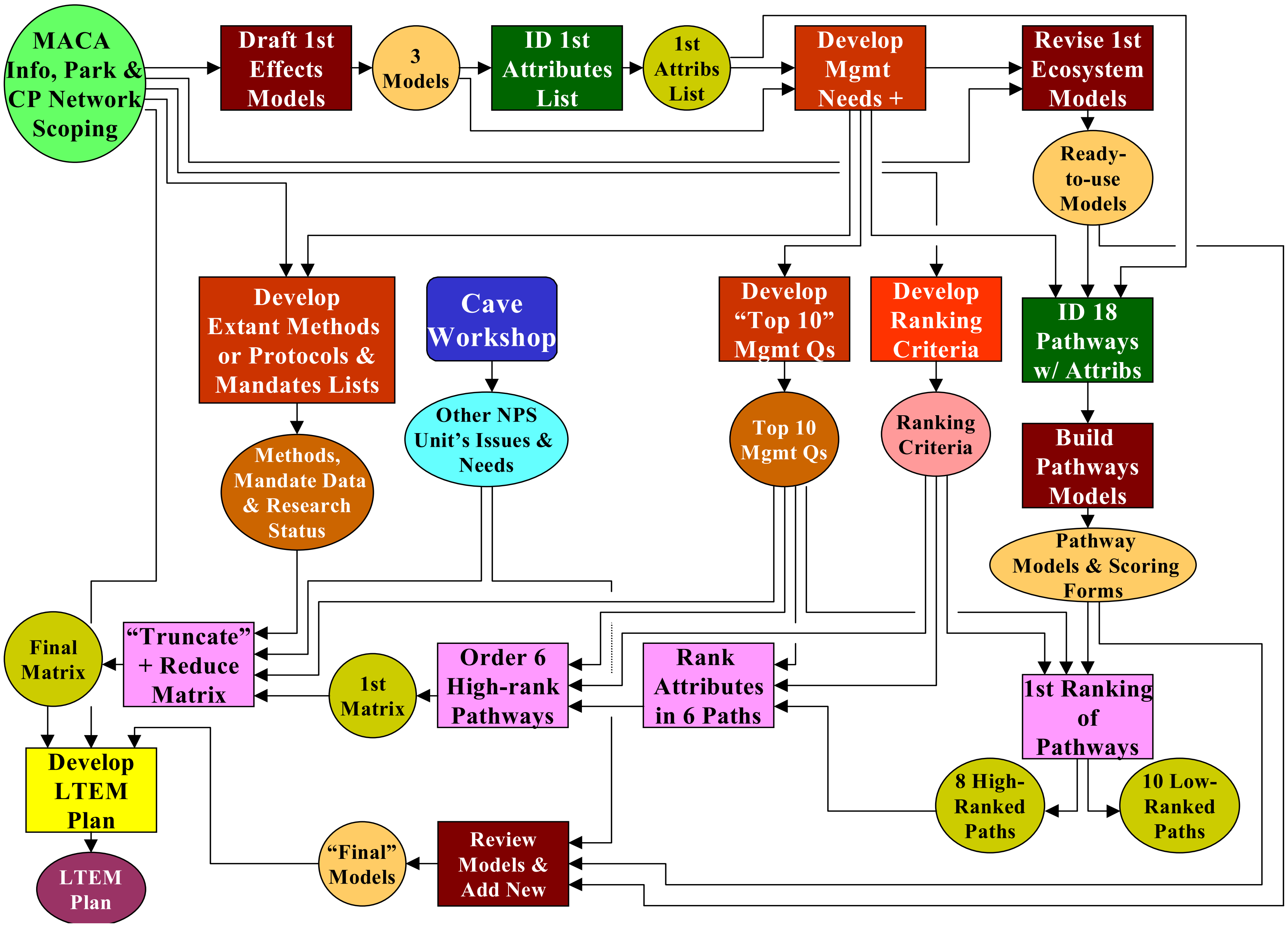


Following the prioritization of the attributes within each of the six higher-priority pathways, the LTEM team completed the pathways ranking by applying “Subjective scoring value” (scoring based upon their individual evaluations of each pathway) in a recorded, individual poll. This scoring served to shuffle the hereto-fore random order of pathways into a series ordered by rank-scoring into the revised, raw “Pathways X Attributes” matrix.

“Round One” resulted in two **products**: a “raw Pathways X Attributes Matrix”, and a set of “less-important Pathways” (Appendix E). The matrix consists of the six (6) pathways that we conclude would be most worthwhile and valuable to monitor, arranged in descending order (left-to-right columns in the matrix), together with their associated attributes (ranked in descending priority as elements down the pathway-columns). The higher-ranking attributes within each pathway are those that will more likely provide robust insight or connections among ecosystems, contribute to our pathway and systems understanding, are of management relevance and value, and which are thought to be reasonably efficaciously monitored. This matrix was then be forwarded to the LTEM “lead team” for further processing in “Round Two”. The “less-important Pathways” list will contribute to development of a park “research catalog” (Appendix F).

“Round Two” was a sort of “matrix-truncation”, or reduction, process that served to trim or reduce the ranked pathways and attributes matrix. This truncation based upon consideration of whether attributes meet legal and policy mandates, whether an attribute should be classified as a research project as versus a monitoring subject, and in discussion of how the LTEM program may strategically allocate its available monitoring resources. In this round, the “lead team” took the raw “Pathways X Attributes” matrix, and performed a compound task: develop some information on possible available monitoring methods and protocols for each attribute, and evaluate each attribute for whether it meets or involves legal or policy mandates, such as the Endangered Species Act. The “lead team” will used these factors, together with discussion of what is currently known about the attribute, to consider whether an attribute should be dropped from the matrix. (An attribute was considered for being dropped from the matrix if it is actually appeared more appropriate, for instance, to consider it a research subject, as versus a monitoring subject, due to lack of demonstrated detailed knowledge and/or lack of extant monitoring, as versus research, methods.) This selection process did not shift the ranked order established for pathways and attributes in “Round One”, but did lead to deletion of some attributes and pathways from the monitoring matrix table. The **final product** of Round Two was a truncated version of the prioritized pathways and attributes matrix (see Appendix G). Attributes dropped from the matrix in Round Two were placed into the park “research catalog” for further development.

Figure 16. Attribute ranking and prioritization process for Mammoth Cave National Park's prototype monitoring program.



4. Outcomes of the MACA attributes identification and prioritization process

The MACA attributes identification process yielded two important products; a ranked and ordered "Pathways X Attributes" matrix, and a list of lesser-ranked Pathways and ecosystem attributes that, for any of several reasons, were identified as being less suitable for or appropriate for monitoring within MACA's program. The matrix product was the functional goal of the attributes identification process. It identifies a defined group of "Habitat Pathways" and associated ecosystem components (attributes) that have been selected as being of salient value to MACA management, able to provide a diverse "indicator perspective" into the functional status and trends in MACA's ecosystems, and able to be effectively monitored within a limited and focused program. The "Pathways X Attributes" matrix identifies the components that the MACA LTEM Program will focus its implementation efforts on in the next several years. From the matrix, the MACA LTEM Program has identified (9) monitoring protocols that will be developed for the program by the USGS/BRD (see Protocols Being Requested). The matrix also identifies additional attributes that are being, or will be, monitored under previously-developed protocols. The list of ten "lesser-importance" Pathways, along with several attributes that were identified as being in need of further research and base-line methods/information development, are being incorporated into a MACA Research Catalog. This catalog will identify a variety of ecological and resource questions, including many which may become future LTEM monitoring projects, that are in need of further research work. Significant development of the MACA Research Catalog is anticipated to start up in FY 2004, following establishment of the MACA LTEM Program's protocol development phase.

C. Monitoring Program Framework and Protocol Development

The finalized matrix (Appendix G) produced by the attributes identification process identifies the ecological monitoring components that will tracked by the MACA LTEM Program in its initial implementation phase. Several significant attributes are identified for each of the three major ecosystems described on the park. Monitoring this set of attributes will, in composite, provide the MACA LTEM Program with a diverse set of ecological data that will reflect the functional state or condition of the park's ecosystems. The data sets collected in the first monitoring implementation-year or season will provide a composite view of current ecosystem condition and the status of several major resources- a "Base-line" reference for interpreting data obtained in the subsequent monitoring seasons and years. "Out-year" monitoring will provide the LTEM Program management with a dynamic view of the trends and shifts (if any) that appear in the condition of park resources and ecosystems. Analysis of these "trends data" will provide the major information needed to detect changes in resource condition and ecosystem function over time.

The "Functional Framework" of the MACA LTEM Program can be described as follows: Seventeen (17) ecosystem components/attributes have been identified for monitoring within the initial implementation phase of the program (Table 4). For each component, a set of specific and detailed monitoring questions will be developed. These questions will identify "response variables" or specific measures and properties that will serve as indicators of attribute status and trends. A monitoring protocol will be implemented for each component to address its set of monitoring questions. Each monitoring protocol to be implemented will be a peer-reviewed, statistically-valid, qualitative and quantitative sampling project which will provide sampling methodology and analytical designs to yield rigorous and reliable data on the component being addressed. Once it is fully field-implemented, the MACA LTEM Program will consist of (17) concurrently-running ecological monitoring projects, each being the operational or applied implementation of the specific protocol and its methods and analytical design.

The MACA LTEM Program will proceed in two phases over the course of FY 2004-2006: The formal "Protocols-Development phase" will occur in FY 2004 and FY 2005. The "Protocol-Implementation phase" will begin with first-year field trials of several protocols in FY 2005, with full implementation of all seventeen planned protocols anticipated for FY 2006.

In the "Protocol-development phase", protocols will be identified and developed or adopted for each of the identified components and its monitoring questions. (For some components, monitoring protocols already exist and are in limited implementation on the park, i.e., Cave Aquatic Fauna IBI.) Protocol development/adoption/review will begin in FY 2004, and is slated for completion by the end of FY 2005. This phase includes the development or adoption of nine (9) new protocols, and the scheduled review of 4 extant protocols already in limited implementation on the park. Primary responsibility for the development and testing of the nine new protocols lies with the USGS- BRD, who are tasked to provide tested and verified monitoring protocols under the MOU. For some attributes (i.e., Hemlock Wooly-Adelgid monitoring and detection), tested and verified monitoring methods and designs are available for adoption by the MACA LTEM Program. In these cases, methods and designs adopted for use on the park will be reviewed and revised (i.e., "tweeked"), if necessary, and fit into park-specific sampling designs for implementation. Extant and currently-implemented monitoring methods and protocols, such as that being used for tracking MACA's Cave Aquatic Fuana (Pearson IBI), will be technically reviewed for appropriate sampling design and methodology by USGS-BRD, and revised, if necessary, for future implementation within the MACA LTEM Program. The "Protocol-Development phase" will be a shared task involving USGS-BRD and NPS (MACA LTEM and SRM) scientists and staff working in a collaborative framework. Full involvement of MACA personnel in all phases of protocol development is essential to ensuring adequate preparation of MACA staff to assume full "on-the-ground" application responsibility in the "Protocol Implementation phase".

To facilitate completion of the "Development" phase, protocol development and review support was formally requested from USGS-BRD in a memo (dated 12 September 2003) identifying nine protocols to be either developed "de-novo", or adopted in whole or in part. This memo proposes four (4) protocols to begin development in FY 2004, with the remaining 5 to begin in FY 2005. In addition to the protocols to be developed or adopted, the memo identifies the four (4) extant protocols that MACA would like to have reviewed by USGS-BRD. These reviews are requested for completion by the end of FY 2005.

The "Protocol-Implementation phase", slated to begin in FY 2005 with initial field tests of newly designed and adopted protocols, will be the functional phase of the MACA LTEM Program. This phase will, when completely developed, involve concurrent implementation of all established protocols, analysis of data and interpretation of resource status and trends results, and provision of technical information to park management. The "Implementation" phase will include periodic review of monitoring efforts and data sets to assess program effectiveness, assess possible resource trends, and to make possible changes in protocol design and/or implementation scales and frequencies. Implementation of protocols will be the responsibility of the MACA LTEM Program, its staff, and diverse associated personnel (e.g., other NPS staff, student interns, seasonal staff, volunteers, contractors). Initial protocol review is recommended to begin ca three-to-4 years after first implementation of the tested design. Protocol and monitoring-outcomes review will be an on-going effort which should involve MACA staff working together with diverse other subject-matter experts to continually re-evaluate the effectiveness and relevance of the LTEM Program and its products as a resource for the park and for the NPS, as a whole.

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PART 2. SUMMARIES OF MONITORING COMPONENTS

The following section summarizes the monitoring components and protocols that are proposed for inclusion in the MACA prototype LTEM program. The elements are arranged according to ecosystem type. Each summary includes a statement of the major problem being addressed by the protocol, a reference for key drivers and stressors, a list of monitoring questions, general monitoring approach to be developed, and a statement of management implications that may result from implementation of the protocol.

Table 4. Ecosystem components/attributes of the Mammoth Cave prototype program

Cave, Terrestrial, and Aquatic Ecosystems

Landscape Monitoring

1. Adjacent land use

Cave Ecosystem

Community Monitoring

1. Cave stream/river aquatic invertebrates and fish (community IBI)

Population/Multiple Populations Monitoring

1. Cave cricket (*Hadenoecus subterraneus*) abundance and distribution
2. Egg predator beetle (*Neaphenops tellkampfi*) abundance & distribution
3. Allegheny woodrat (*Neotoma magister*) population dynamics
4. Summer cave-roosting bat populations and usage of caves
5. Hibernating bat populations and usage of caves

Environmental Monitoring

1. <u>Cave</u> and surface stream/river water quality
2. Core methods for air quality monitoring in the cave system

Terrestrial Ecosystem

Population/Multiple Populations Monitoring

1. Ozone-sensitive plants
2. Acid pH-sensitive plants
3. Early detection and distribution--monitoring of hemlock wooly adelgid

Environmental Monitoring

1. Local weather and air quality

Aquatic Ecosystem

Community Monitoring

1. Fish diversity in the Green and Nolin Rivers
2. Mussel diversity in the Green River
3. Muskrat predation impact on mussel diversity in the Green River
4. Green River benthic macroinvertebrates (community IBI)

Environmental Monitoring

1. Cave and <u>surface</u> stream/river water quality

1. Adjacent Land Use

Problem Statement and Justification

Mammoth Cave National Park exists as an island in a largely rural-but-changing landscape in South-central Kentucky. Adjacent lands on all sides of the park include a diverse mosaic of forested areas and wood-lots, small farms, rural and moderately-urbanized residential areas, and towns and small cities. This adjacent landscape includes active railroads (CSX route lies to the East and South of the park , crossing Hart, Barren and Warren Counties), a main corridor super-highway (Interstate 65), and many miles of state and county/local roads. Important current land-usage includes farming (tobacco, corn, soy), small-scale timber-cutting, horse, cattle, pig and fowl-rearing and feed-lot operations, and a range of domestic-residential and industrial developments. Land-use patterns are changing in this region, as in most areas across the country. Urban populations are growing, adjacent farm-lands are being converted to residential, industrial, and recreational uses (i.e., golf courses), and development of a planned regional transportation center and airport in Warren County (the Transpark project) are anticipated for the near future. Current land-use poses many threats at several levels to the park and its natural resources. Some of these include ecological threats to the park's biodiversity resulting from on-going habitat fragmentation, water-borne contaminants from chemical spills, roadway and railroad run-off, industrial, urban/residential and agricultural waste and run-offs, and air-borne contaminants from agricultural herbicides and pesticides, industrial stack-emissions, and automotive exhaust gases. Other sources of impact to the park's resources may include effects from the Green River Conservation Reserve Enhancement Program affecting land-use adjacent to the Green River upstream of the park, and increases in park visitation resulting from increased local populations. In general, on-going urbanization and industrial development in adjacent lands is likely to exacerbate the diversity and magnitudes of threats to the park's ecosystems. These over-arching concerns are a strong focal point for park management, and will remain a significant concern into the foreseeable future.

Model of Key Drivers

Adjacent land-use affectors (stressors) are depicted in the general ecosystem and Pathways models developed for the LTEM Program. Anthropogenic stressors known or believed to be affecting the park's ecosystems are described in the Introduction, section B (Natural Resources), and depicted in the three Ecosystem Effects models (Figures 10, 11, and 12), and in the "Surface Factors" model developed to support the set of "Pathways" models used in the MACA attributes identification process (Figure 13).

Monitoring Questions and Approach

1. How has adjacent land use changed since park establishment?
   Specific monitoring approaches remain to be developed. Possible approaches include analysis of extant photographic records of the park and near-adjacent lands, and analysis of local and regional land-use records to construct historical and current depictions of adjacent land-use patterns.
2. How is adjacent land use changing over time?

A likely method for monitoring change over time in land-use patterns will be to design and implement a periodic photographic documentation and photo-analysis program for lands in the near-park region.

Management Implications

Monitoring data will provide information that will affect park management's ability to comment on or address watershed and adjacent land use changes and issues.
Monitoring data will contribute to management's understanding of invasive exotic species on the park.
Monitoring data will contribute to management's understanding of population dynamics of animals influenced by habitat fragmentation (e.g., woodrats).

2. Cave Stream/River Aquatic Invertebrates and Fish Community IBI

Problem Statement and Justification

An important feature of Mammoth Cave National Park is the presence of perennial cave streams and rivers in several sections of the cave system. These cave rivers support an important and unique aquatic fauna, including highly cave-adapted fish, shrimp, and crawfish species, together with amphipods and isopods. Cave rivers, and their included fauna, are vulnerable to diverse threats that impact surface water quality and flow-regimes into the caves, including impacts from air- and water-pollution, flow-modifications in the Green River, and diverse changes in adjacent-land use. Cave river fauna may also be sensitive to cave management practices, and to disturbance from cave visitors, including tourists, park staff, and researchers. Other potential threats are posed by epigean species and, in particular, exotic trout introduced for sport-fishing in the Green River. This fauna represents a dynamic and living system and comprises a valuable set of park resources. The importance to the park of its cave river aquatic fauna is enhanced by the presence of Federally-listed "T & E" species. These species impose additional monitoring responsibilities upon the park under the provisions of the Endangered Species Act and…(park legislation???). At present, cave river fauna are being monitored on the park using a community-based "IBI" methodology and monitoring schedule developed for the park by W. Pearson (Pearson and Jones 1998). This protocol has been identified for technical review and evaluation by USGS-BRD in FY 2004 or FY 2005.

Model of Key Drivers

Natural drivers and generalized anthropogenic stressors affecting cave rivers and their fauna are described in the Introduction, section B.1., and depicted in the General Cave Ecosystem Effects model (Figure 10).

Monitoring Questions and Approach

1. What is the trend over time in the population structure and relative abundance (via an IBI) of cave aquatic communities in selected sites on the park? [i.e., How are populations of cave aquatic fauna (e.g., cave shrimp, cave fish, cave crayfish, cave isopods) doing on the park?]
   Current approach: perform low-impact surveys and enumeration of cave fishes, shrimp, amphipods, isopods, and crawfish using methods described in Pearson and Jones (1998).

Management Implications

Monitoring data will provide an evaluation of the park's efforts towards endangered Kentucky cave shrimp conservation.
The IBI will provide index evaluation of changes over time in the functional condition of the cave aquatic ecosystem.
Changes over time in the IBI will provide integrated feedback or early warning of impacts due to changes in the Green River (i.e., water quality and quantity changes).

3. Cave Cricket (*Hadenoecus subterraneus*) Abundance and Distribution

Problem Statement and Justification

Cave cricket abundance and distribution trend data should be of great importance to resource managers throughout many of the National Park Service's (NPS) >100 units with cave and karst features. Mammoth Cave National Park's cave system hosts variably large and widely-distributed populations of two cave-dwelling cricket genera (i.e., *Ceuthophilus* spp. and *Hadenoecus* spp.). These taxa have a high importance value to cave food webs in the United States because they are frequent in time and space, typically dense where they are found, and have a high impact per individual. Crickets are the primary conduits for the input of allochthonous organic matter, in the form of guano, into terrestrial cave ecosystems. This matter supports subsurface communities that include rare, often endemic, obligate cave-dwelling invertebrates (Culver et al. 2000). For example, H*adenoecus subterraneus* subsidizes three distinct subsurface communities with its eggs and feces (Poulson and Lavoie 2000).

In the Mammoth Cave region *Hadenoecus subterraneus* is a key foundation species because it is the basis for three separate terrestrial cave communities. Their feces support the cricket guano community of detritivores and their predators in areas near to cave entrances. A second community is supported in areas with sand or silt substrate where the crickets mate and lay their eggs. Here the crickets indirectly support a community of detritivores and their predators via the feces of a carabid beetle that specializes on eating cave cricket eggs (Poulson 1992). A third community is spread out over the areas that the crickets traverse from the entrance areas to the reproductive areas. Cricket feces deposited on these trips supports a community of energy efficient detritivores and their predators that partially overlaps with the community in reproductive areas (Poulson 1992).

The effects of natural variation (e.g., drought) and management decisions on surface and subsurface habitat (e.g., altering cave entrance configuration, cave visitation, cave lighting, in-cave structural modification) on cricket population dynamics have the potential to affect the flow of allochthonous organic matter into caves (Poulson et al. 1995). Thus, resource managers at NPS cave and karst units with significant cave cricket populations, particularly units with limited base funding, may want to implement long-term protocols to monitor cricket populations as an index of overall robustness of cave terrestrial invertebrate communities.

Model of Key Drivers

Natural drivers and anthropogenic stressors that affect cave cricket population dynamics (Figure 14) and distribution are described in the Introduction, section B.1., and depicted in the General Cave Ecosystem Effects model (Figure 10).

Monitoring Questions and Approach

1. What is the trend over time in cave cricket populations [<u>relative</u> abundance or density (?), distribution, and structure (age/size class ratios, sex ratios)] in selected caves at MACA? Methods and sampling design are currently in development to address this question.

2. Are the trends in cave cricket populations [relative abundance or density (?), distribution, and structure (age/size class ratios, sex ratios)] the same in all caves or do they differ among the selected caves over time?
   Sampling and analytic designs are currently in development to address this question.

Management Implications

Data documenting trends in cricket population structure and distribution patterns within selected caves will provide park management with insight into the status and potential shifts in ecosystem condition.

Trend data collected in selected caves and correlated with specific drivers and stressors (i.e., cave lights and entrance structures) will yield assessment of management impacts to the park, and provide insight into how cave management practices may be diversely and strongly affecting the functional condition of the cave ecosystem.

4. Egg Predator Cave Beetle (*Neaphaenops tellkampfi*) Distribution and Abundance

Problem Statement and Justification

Neaphaenops tellkampfi is one of the primary sources of egg mortality in populations of the Cave Cricket, *Hadenoecus subterraneus* on Mammoth Cave Natl. Park. Indeed, egg predation rates by *N. tellkampfi* in both field and experimental conditions were as high as 90% (Kane and Poulson 1976, Griffith and Poulson 1993). *Neaphaenops tellkampfi* exhibits relatively high densities in every cave inhabited by cave crickets. *Neaphaenops tellkampfi* also subsidizes a community of cave-dwelling invertebrates through its feces (Poulson 1992). Thus, *N. tellkampfi*'s significant role as both predator and subsidizer in one community of subsurface invertebrates indicates their population dynamics should be of interest for protocol development in MACA's Long Term Ecological Monitoring program.

Previous research showed both abiotic and biotic stressors affected *N. tellkampfi* population ecology. *Neaphaenops tellkampfi* abundance fluctuated significantly within years in caves with severe temperature and/or humidity depression in winter (Kane and Ryan 1983). Caves with large fluctuations in *N. tellkampfi* abundance also typically experienced some flooding or seepage (Kane and Ryan 1983). Water input into caves undoubtedly contributed to increased availability and diversity of food sources (i.e., small invertebrates) for *N. tellkampfi.* Indeed, the only cave in Kane and Ryan's (1983) study without winter temperature/humidity depression and no water input had relatively stable, but low, *N. tellkampfi* abundance. Most of the caves in Kane and Ryan's (1983) study were outside MACA boundaries and as such were not affected by management actions on cave openings. Thus, long-term monitoring of *N. tellkampfi* subpopulations among both developed and undeveloped caves in MACA, and the effects of management actions on those subpopulations, has yet to be done. Previous efforts to monitor subsurface communities only noted the presence of *N. tellkampfi* despite habits that suggest their populations could be monitored relatively easily.

Model of Key Drivers

Natural drivers and anthropogenic stressors affecting the relative abundance and distribution of cave beetles within selected caves are described in the Introduction, section B.1., and depicted in the General Cave Ecosystem Effects model (Figure 10).

Monitoring Questions and Approach

1. What is the current distribution and relative abundance of *Neaphaenops tellkampfi* populations within selected "high cricket density" caves in the park?
   Cave beetle distribution and abundance will be sampled in selected areas in selected caves to provide baseline data on current abundance and distribution status.
2. How are *N. tellkampfi* relative abundance and distribution patterns changing over time in selected caves in the park?
   Cave beetle distribution and abundance will be monitored across time (seasons and years) in selected areas of selected caves to provide trends within and among areas and caves sampled.

Management Implications

- The proposed monitoring methodology will efficiently provide reliable data on *N. tellkampfi* population abundance and distribution over time. These data will contribute to further delineate ecological relationships between *N. tellkampfi* and cave crickets, and contribute functional understanding of the dynamics of cave crickets within the cave ecosystem.
- The protocol developed for this species could likely be adapted for monitoring MACA's other cave-dwelling beetles (including the Federally-listed *Psuedonophthalmus*).
- This protocol will be exportable to other National Park Service cave and karst units, where similar beetle species are thought to exist, and to constitute important ecological resources to be monitored for functional understanding of those ecosystems.
- Data on cave beetle distribution and abundance will contribute leads for future directions for basic research into cave community and ecosystem dynamics.

5. Allegheny Woodrat (*Neotoma magister*) Population Dynamics

Problem Statement and Justification

Allegheny woodrats are vital to the cave ecosystem in Mammoth Cave National Park (MACA) for reasons such as: 1) they are relatively common, occurring in many caves in the park; 2) they support a specialized invertebrate cave community (Richards 1989, 1990); and 3) they import organic material (e.g., plant material, fungi, feces) into the cave ecosystem.

Allegheny woodrats are an endemic forest-dwelling species associated with cliffs, rock outcrops, talus slopes, and caves. Because woodrats are limited to rocky habitats for dens and to forests for food (especially nuts and acorns), they are vulnerable to disturbance both within caves and in the surrounding forest. Due to dramatic population declines along the northern and western peripheries of the species' range over the past 30 years they now occur on more state endangered and threatened species lists than any other rodent in the U.S. The Allegheny woodrat is currently monitored by the Natural Heritage Program as a G3/G4 species (i.e., "vulnerable"/"apparently secure", and is considered a "species of concern" (formerly called "Category 2 candidate") by the U.S. Fish and Wildlife Service.

Specific threats to woodrats at MACA include cave entrance modification, direct visitor disturbance, cave lighting impacts, raccoon roundworm parasite (lethal to woodrats), impacts to food resources [e.g., pests/pathogens (hard mast species), ozone, pH, fire], habitat fragmentation/loss (adjacent land use), in-cave modifications, and an increase in predators (e.g., feral cats, skunks, owls).

Model of Key Drivers

Natural drivers and anthropogenic stressors affecting population dynamics and distribution of woodrats (Figure 15) on the park are described in the Introduction, section B.1., and are depicted in the Terrestrial and Cave General Effects Models (Figures 4, and 6).

Monitoring Questions and Approach

1. What is the status of Allegheny woodrat populations [size (N) estimate, distribution, and structure (age/size class ratios, sex ratios)] at the park?
   For monitoring questions 1 – 4; sampling designs and methodology are currently in development.
2. What is the trend over time in Allegheny woodrat populations [size (N) estimate, distribution, and structure (age/size class ratios, sex ratios)] at the park?
3. What is the current pattern (status) in cave use by Allegheny woodrats among caves on the park?
4. What is the change in the pattern (trend) of cave use by Allegheny woodrats among caves on the park?

Management Implications

Allegheny woodrat cave use data will give park managers insight into management actions in order to mitigate negative impacts.
Monitoring the Allegheny woodrat populations on the park will provide early warning of possible problems with lethal parasites associated with raccoons.

6. Summer Cave-Roosting Bat Populations and Usage of Caves

Problem Statement and Justification

In recent history (<500 years BP), several of the caves at Mammoth Cave National Park (MACA) were home to perhaps thousands of summer roosting bats. Bats have virtually abandoned the Historic Entrance Area of Mammoth Cave due, in part, to a combination of human activities including direct disturbance during the summer. At present, approximately five caves at MACA have small (<100) summer bachelor colonies of federally endangered gray bats (*Myotis grisescens*). This listed species constitutes a special biological resource for the park, and imposes specific monitoring responsibilities upon park management. Four caves/rockshelters (and occasional man-made structures) at the park are known to contain small (<50) to relatively large (~200) colonies of Rafinesque's big-eared bats (*Corynorhinus rafinesquii*). This species, a former "Category 2 candidate" species, is now considered a "species of concern" by the U.S. Fish and Wildlife Service and is listed as "special concern" by the Kentucky State Nature Preserves Commission. Summer roosting bats provide guano to the cave ecosystem, which is an important energy source in an energy sparse habitat.

The park's summer cave bat fauna is subject to several potentially strong anthropogenic stressors; any or all of which may severely impact bat success in the caves. These include historic and on-going human disturbance, modification of cave entrances, changes in cave atmospheric conditions, on-going mercury accumulation from atmospheric pollution, and chemical accumulation from pesticide applications outside the park boundary.

Model of Key Drivers

Natural drivers and anthropogenic stressors affecting summer use of caves by Gray bats and Rafinesque's big-eared bats are described in the Introduction, section B.1., and depicted in the General Cave Ecosystem Effects model (Figure 10).

Monitoring Questions and Approach

1. What is the status (estimated size and distribution) of the park's summer populations of cave-roosting bats (gray bat and Rafinesque's big-eared bat)?
   Bat populations will be sampled and abundances estimated in known summer-use caves to provide initial baseline abundance and distribution data.
2. What is the trend in the park's summer populations of cave-roosting bats (gray bat and Rafinesque's big-eared bat)?
   Bat populations will be monitored across years in several known summer-use caves to provide trend data for summer bat populations in selected caves.

Management Implications

The functional role of summer populations of bats in the cave ecosystem, the presence of one T & E species and one species of concern on the park, their potential for reflecting any of several possible threats to the cave ecosystem, and the availability of several potentially effective management actions make summer cave-roosting bat populations valuable and of special interest for monitoring within MACA's Long-Term Ecological Monitoring Program. Monitoring summer cave-roosting bat populations parameters (population size, distribution, productivity) will yield important information that can contribute to developing future management actions aimed at cave resource management and preservation. Possible uses of summer cave bat population and trends data would include identifying actual declines in the resource which would mandate development of management actions to mitigate impacts, and suggest research to identify and address specific factors that affect summer cave-roosting bats. Trend information, coupled with targeted research data, could help support park strategic efforts to reduce mercury emissions from upwind coal-burning power generation plants via the permit review process.

7. Hibernating Bat Populations and Usage of Caves

Problem Statement and Justification

In recent history (<500 years BP), several of the caves at Mammoth Cave National Park (MACA) were home to from thousands to millions of hibernating bats. Bats have virtually abandoned the Historic Entrance Area of Mammoth Cave due, in part, to a combination of human activities including direct disturbance during the summer. At present, five caves at MACA are known to have hibernating colonies of federally endangered Indiana bats (*Myotis sodalis*) that range from 30 to 3,600 bats, and two caves with hibernating colonies of endangered gray bats (*M. grisescens*) ranging from 500 to 800 bats each. These listed species constitute a special biological resource for the park, and imposes specific monitoring responsibilities upon park management. Four caves/rockshelters (and occasional man-made structures) at the park are known to contain small (<10) to relatively large (~200) colonies of hibernating Rafinesque's big-eared bats (*Corynorhinus rafinesquii*). This species, a former "Category 2 candidate" species, is now considered a "species of concern" by the U.S. Fish and Wildlife Service and is listed as "special concern" by the Kentucky State Nature Preserves Commission. Hibernating bats provide relatively little and diffuse guano to the cave ecosystem, which does serve, along with occasional carcasses, as an energy source in an energy sparse habitat.

The park's hibernating cave bat fauna is subject to several potentially strong anthropogenic stressors; any or all of which may severely impact bat success in the caves. These include modification of cave entrances, direct visitor and researcher disturbance, changes in cave atmospheric conditions, impacts of cave lighting, in-cave structural modifications, smoke from surface fires, and noise disturbance outside of caves.

Model of Key Drivers

Natural drivers and anthropogenic factors affecting hibernation of bats in the park's caves are described in the Introduction, section B.1., and depicted in the General Cave Ecosystem Effects model (Figure 10).

Monitoring Questions and Approach

1. What is the trend over time in rare/endangered hibernating bat relative abundance in, and usage (distribution) of, the park's known hibernacula caves?
   An extant protocol is in place at the park to census bats in known hibernacula.
2. Is there a correlation between cave temperature and relative humidity trends and hibernating bat relative abundance in, and usage of, the park's known hibernacula caves?
   Data collected from bat censuses in known hibernacula will be analyzed in correlation with air quality data collected in caves under the auspices of the "Cave Air Quality" monitoring protocol.

Management Implications

Monitoring data will provide feedback on the impacts of cave management actions on species of rare and endangered hibernating bats.
Monitoring data will provide limited evaluation of the park's efforts toward endangered bat species conservation.

8. Cave and Surface Stream/River Water Quality

Problem Statement and Justification

Water is a key resource for Mammoth Cave National Park. Water, and water quality, affect and drive all 3 ecosystems described within the park, and, further more, serves to tie the ecosystems together into a functional whole, through vital transport of nutrients, provision of natural habitats, and conveyance and distribution of chemical and physical threats and stressors. Park water quality is impacted by a wide range of "point-source" and "non-point-source" contaminants, plus up-stream flow regime alterations in the Green River, and development of adjacent land-use. Park water-resource issues are generally divided between surface waters, focused around the Green River and diverse ponds and streams, and cave-associated waters (mainly cave rivers and inputs into the cave and karst system). Surface waters support diverse vertebrate and invertebrate fauna in the Green River, including significant diversities of fishes and fresh-water mussels. Water-borne contaminants and changes in river flow regimes have enormous potential to adversely affect many of these species, including several Federally-listed mussel species. Surface water quality and flow regimes can, in turn, strongly affect water quality and flow regimes throughout the cave ecosystem. Cave rivers support diverse and unique aquatic fauna, including Federally-listed cave shrimp. Water quality issues are not unique to MACA- in fact, water and water quality is a central issue across the NP Service, and is the focus of a large and growing monitoring program being pursued at several levels across the region and the country. Mammoth Cave National Park currently has in place a synoptic, non-conditional water-quality monitoring program and protocol for surface-water monitoring In addition, limited water-quality monitoring is being performed within the park's cave rivers. The park's program bases upon standard methods and follows established NAWQA standards. The MACA cave and surface water-quality monitoring program will be reviewed for adequacy of sampling designs in FY 2004 or FY 2005 by USGS-BRD.

Model of Key Drivers

Natural drivers and anthropogenic stressors affecting surface and cave water quality are described in the Introduction, sections B.1. and B.2., and depicted in the Cave and Aquatic Ecosystem Effect models (Figures 4, and 5).

Monitoring Questions and Approach

1. How is the park's water quality (e.g., silt, chemistry, nutrients, pesticides, metals) changing over time?
   Perform synoptic, non-conditional water quality sampling using in-place NAWQA standards and appropriate sampling designs. Sampling design is to be reviewed in FY 2004 or FY 2005.
2. How is the park's water quality changing with respect to changes in regional water quality?
   Compare quantitative and qualitative data from the MACA water quality monitoring program with data collected in adjacent and regional water quality monitoring programs.

Management Implications

- Monitoring data will provide the park with habitat and food resources assessment that will contribute to conservation of endangered aquatic fauna.
- Monitoring data will contribute to the park's understanding of trends in fish diversity and abundance.
- Monitoring data will contribute to the park's understanding of trends in Green River benthic macroinvertebrate diversity and abundance.
- Monitoring data will provide information that will affect park management's ability to comment on or address watershed land use changes and issues.

9. Development of Core Methods for Monitoring Cave Air Quality

Problem Statement and Justification

Mammoth Cave Natl. Park's cave system supports a complex ecosystem with many special biotic and abiotic components. Biotic components include bats (including two endangered species), woodrats, beetles, and crickets. Cultural and natural abiotic components consist of items such as wooden War of 1812 saltpeter leaching vats, Native American artifacts, and geological processes such as speleothem development. Cave air quality is a key "driver" in the cave ecosystem as it has direct impacts on both biological and cultural resources contained in the cave system. Also, cave air quality is directly and significantly impacted by management decisions and actions (i.e. cave gate installations) as well as by visitor use. Because of their key roles and impacts on cave resources and their responses to management actions, cave atmospheric parameters such as air temperature, relative humidity, mass flux of air, and carbon dioxide levels are of special interest for monitoring within MACA's Long-Term Ecological Monitoring Program.

Measurement of cave air quality is an important way to assess status of various cave biota and abiotic cave components. It is desirable, for many reasons, to develop a method for the determination of the optimal placement of a single instrument package within a cave space. Establishment of a "single best placement instrument package" eliminates the need for a network of monitoring packages (which would be expensive and time consuming to maintain as well as intrusive) within a cave space. The challenge facing MACA is the need to efficiently measure cave air quality within cave spaces and do so in a way that is comparable from one cave space to the next. A large difficulty in measuring cave air quality is that air quality parameters can be non-uniformly distributed within cave air spaces. Cave spaces where air quality parameters have non-uniform values across their spaces (most cave spaces) generally cannot be accurately characterized by a single instrument package. The use of multiple instrument packages would be most desirable in these cases, but the cost of equipment and maintenance of such a network is prohibitive. A spatial model of cave air quality parameters would make it possible to use a "best-placement single instrument" model within such a space and to extrapolate conditions within the space using the information collected with that single instrument package.

Model of Key Drivers

Natural drivers and anthropogenic stressors that affect air quality and flux within the cave ecosystem are described in the Introduction, section B.1., and depicted in the General Cave Ecosystem Effects model (Figure 10).

Monitoring Questions and Approach

1. What is the best location from which a single instrument package could monitor cave air quality within a cave space (two-dimensional or three-dimensional) where cave air quality parameter measurements are non-randomly distributed?
   Design and implement an instrument array to sample the airspace, and develop a cross-sectional air-flow model for that space which will enable identification of a single monitoring

point and support extrapolation of air-flux for that space. A general cross-sectional extrapolation model, applicable to a variety of cross-sectional areas, would be the ideal product.

2. What is the best location from which a single instrument package could monitor cave air quality within a cave space (two-dimensional or three-dimensional) where airflow is turbulent and air quality parameter measurements are randomly distributed?

   Design and implement a sampling array to identify a single useful instrument location within that space, and develop an air-flux model that supports extrapolation of air-flux across the selected space. Ideally, a general instrument-placement and extrapolation model will be developed for use in a variety of cave spaces.

Management Implications

Status and long-term trends in cave air quality parameters would be essential in determining a cave's response to management actions such as entrance modifications or other changes to cave structure and morphology.

Data on of cave air parameter values will provide valuable correlative information contributing to cave cricket, beetle, woodrat and other cave-related monitoring projects within MACA's Long-Term Ecological Monitoring Program.

Cave air quality data will contribute to park management efforts toward conservation of Federally-listed bat species.

10. Ozone-Sensitive Plants

Problem Statement and Justification

Air pollution and in particular, ozone, poses a significant threat to the natural resources and public health at Mammoth Cave National Park (MACA). This widespread air pollutant has been reported to cause diverse types of injury to native vegetation. Many species of plants, including forest trees and native wildflowers, exhibit visual injury to foliage at current ambient levels of ozone. A long standing issue among ecologists has been the relationship of these visual changes at the leaf-level to subtle shifts in plant growth, competition, and interactions with the biotic and abiotic environment that are expressed at the whole plant level. Based on an analysis of species sensitivities and pollutant levels, of the 48 Class I Air Quality national parks, the Air Resource Division ranked MACA as the park most sensitive to air pollution regardless of size. When the MACA flora was compared to a Synthesis species list developed by an expert in the field of ozone impacts on vegetation, eleven species of MACA plants were identified as being "highly sensitive to ozone". These species are common to the southeastern United States and occur at other National Parks in the region.

Plants exhibit ozone foliar injury symptoms after accumulative exposure to ozone. The SUM06 statistic is used to evaluate the risk of plant injury. This expresses the sum of all hourly average ozone concentrations greater than or equal to 0.06 ppm. All parks in the Cumberland/Peidmont Network experience ozone concentrations high enough during some years to sustain foliar injury to park vegetation. Standards and a scale for visually assessing percent foliar injury have been developed and are being used at Great Smokey Mountains National Park. By linking passive ozone monitoring with symptoms of ozone injury, ozone impacts can be assessed over time and across the landscape.

Model of Key Drivers

Natural drivers and anthropogenic stressors, including Ozone, that affect native plant populations and communities on the park are described in the Introduction, section B.3., and are depicted in the General Terrestrial Ecosystem Effects model (Figure 12).

Monitoring Questions and Approach

1. What are the current levels of ozone damage (stipling, necrosis, reproductive rate, growth rate, chlorophyll levels) in the park's populations of the perennial herbaceous species *Rudbeckia lanciniata and Verbisina occidentalis*?
   Questions 1 and 3 will be addressed by sampling Ozone-induced foliar damage in selected monitoring plots containing populations of the four sensitive plant species. Sample analysis will yield estimates of percent-foliar damage for each sensitive species.
2. What is the distribution of ozone damage in *Rudbeckia lanciniata* and *Verbisina occidentalis* across the park?
   Questions 2 and 4 will be addressed by sampling Ozone-induced foliar damage levels in four Ozone-sensitive plant species on a statistically-designed sampling grid across the park.

Analysis of sample data will provide distribution estimates and maps of Ozone-damage for each species sampled.

3. What are the levels of ozone damage (stipling, necrosis, reproductive rate, growth rate, chlorophyll levels) in the park's populations of the tree species *Liriodendron tulipifera* and *Prunus serotina*?
4. What is the distribution of ozone damage in *Liriodendron tulipifera* and *Prunus serotina* across the park?
5. What is the trend in ozone damage levels and distribution in these species over time?

   Percent foliar damage will be monitored over time in four Ozone-sensitive plant species on a statistically-designed sampling grid across the park. Foliar damage data will be correlated with Ozone concentration data obtained from the MACA air quality monitoring program.

Management Implications

This is especially important to park management because of the outside pressures of additional permit applications for new coal-fired power generating plants in the region. Information on Ozone damage levels and trends will provide support to park management efforts at protecting the park's natural resources through addressing current and future local and regional power-plant development.

Information on Ozone impacts on the park's vegetation is critical for the assessment of ozone pollution effects of natural ecosystems, including those like MACA, that are designated as Class I air quality areas under the Clean Air Act. Data collected will provide an important contribution to the park's understanding of these wide-spread and potentially major effects.

Ozone impact data will support park management efforts to fulfill Clean Air Act and NPS Organic Act responsibilities, and can contribute to other agencies, in their efforts to further develop air quality standards and policy at local, regional and national levels.

11. Acid pH-Sensitive Plants

The landscape of Mammoth Cave National Park (MACA) is mainly comprised of mixed mesophytic forest underlain by sandstone and limestone. MACA is listed as a Class One Air-shed. It is also subject to some of the most significant and chronic air pollution documented in the United States. Indeed, it is ranked as being amongst the five most severely impacted parks and ecosystems within the National Park Service, and suffers damage from high Ozone levels and significant levels of Nitrogen and Sulfur- (acid-producing) air contaminants. Studies indicate that different ecosystems, plant communities, and even different plant species respond to atmospheric acid deposition in different ways (Eagar 1996, Cox 1984, Tilman 1995, Winner 1994, Shevtsova and Neuvonen 1997). Acid rain is expected to have greater impacts on acid soils than on limestone soils, which are expected to buffer acid rain (Mather 1990). The park has been monitoring acid precipitation, ozone, and visibility data since 1991. The Kentucky Division for Air Quality has been measuring wet deposition concentrations in the park since 1983. The combined annual nitrate and sulfate deposition at MACA for the past nine years averages 39.5 kg*$ha^{-1}yr^{-1}$. The impact of such rates of deposition on soils and herbaceous plant communities is not clear, but we would expect to see changes in the composition of the plant community and changes in the reproductive status of individual plant species.

Model of Key Drivers

A generalized model and discussion of threats to MACA's air quality are presented in the Introduction, section B.3. Acid deposition is one of several air-quality-related threats depicted in the General Terrestrial Ecosystem Effects model (Figure 12).

Monitoring Questions and Approach

1. What is the current level of acid-pH-related damage in the park populations of pH-sensitive plant species (specific species to be determined)?
   Damage levels related to acid-pH will be assessed using foliar damage and, possibly, another metric, assessed on statistically-determined plant samples within designated plots containing pH-sensitive plant.
2. How are pH-related damage levels changing over time in the park populations of pH-sensitive plant species (specific species to be determined)?
   Damage levels will be monitored in selected plots of pH-sensitive plants on an annual basis. Trends in foliar damage levels will be correlated with acid-deposition data obtained from the park's air quality monitoring program.
3. How does soil pH change over time at acid-pH sensitive plant monitoring sites?
   Soil pH and selected soil chemistry parameters will be monitored at pH-sensitive plant plots using standard soil-sampling and analysis methods. Data will be analyzed for correlation with major substrate (i.e., limestone or sandstone, etc.), and with acid deposition data obtained from the park's air quality monitoring program.

Management Implications

Acid-pH and acid deposition in precipitation pose diverse and severe threats to the MACA ecosystem. Information on acid-pH impacts on the park's plants species will contribute to understanding of this threat and its real impacts.

Information on acid-pH impacts will contribute to park management efforts to address local and regional air pollution issues, and to their efforts at protecting the park's natural resources.

12. Early Detection and Distribution--Monitoring of Hemlock Wooly Adelgid

Problem Statement and Justification

Mammoth Cave National Park (MACA) consists of approximately 53,000 acres of mixed mesophytic forest. This forest supports many tree species that have been or potentially will be impacted be exotic pests and pathogens. The American chestnut, that once comprised about 25 percent of the Mammoth Cave upland forest, has been reduced to remnant root sprouts by an exotic fungal pathogen introduced from Asia in the early 1900's. While some pests are species-specific, such as the chestnut pathogen, others such as the gypsy moth are known to feed on over 300 different plant species. Hemlock Wooly Adelgid (a homopterous insect pest related to aphids) is currently impacting eastern hemlock throughout eastern North America, and is considered by the USDA Forest Service to be the single greatest threat to the health and sustainability of hemlock as a forest resource. In New Jersey forests a monitoring program has revealed that the rate of mortality is as high as 90 percent 10-12 years after initial infestation.

Eastern hemlock coves comprise the smallest land area of seven forest types recognized at Mammoth Cave National Park. This community is limited by physiographic and moisture conditions to the upsteam ends of Casseyville sandstone coves of early Pennsylvanian age. The ecological impacts of the loss of eastern hemlock from the Mammoth Cave ecosystem are broad and far-reaching. Hemlock coves provide a distinct microclimate which adds to overall biodiversity. High adelgid infestation levels may be expected to cause declines in aquatic insects, fishes, and birds in relation to hemlock loss.

Model of Key Drivers

Hemlock wooly adelgid is identified within the terrestrial ecosystem model. Its role as a potential serious pest and threat to the park's Eastern Hemlock population is described in the Introduction, section B.3., and depicted in the General Terrestrial Ecosystem Effects model (Figure 12).

Monitoring Questions and Approach

1. What is the current infection level and distribution of hemlock wooly adelgid in the park?
   Baseline adelgid invasion and infestation will be assessed using census and sampling methods adapted from the wooly adelgid detection and monitoring protocol currently being implemented at Delaware Water Gap.
2. How are infestation levels and distribution associated with the park's populations of eastern hemlock changing over time?
   Spread and distribution of hemlock wooly adelgid will be monitored over time using annual sampling methods adapted from the adelgid detection and monitoring protocol currently being implemented at Delaware Water Gap.

Management Implications

- Data regarding incidence rate and distribution of wooly adelgid will be used to guide park management in protecting park resources through early detection.
- Initial predictions and recommendations based on monitoring data will allow park managers to take management actions to mitigate these impacts.

13. Local Weather and Air Quality

Problem Statement and Justification

Air quality is a nation-wide issue, both for its relevance to human health issues and concerns, and for its manifest and diverse impacts on many components of ecosystems across the country, and indeed, over the surface of planet Earth. Air quality is a central issue for Mammoth Cave National Park, which is designated as a Class 1 Air-shed. Poor air quality, as measured by high concentrations of chemical pollutants and particulates, poses a diverse threat to many components of the park's terrestrial ecosystem, and also severely impacts water quality. Significant air-quality-related threats at MACA include high Ozone levels, atmospheric transport and precipitation of Mercury and other metals, and chronic deposition of acid-forming ions. These contaminants adversely affect visitor experiences, surface water quality, impact soil chemistry, and directly impact many plant species found on the park. The diversity of impacts suffered by the park from deteriorating air quality, coupled with the park's status as a Class 1 Air-shed (and thus protected by provisions of the Clean Air Act), and proximity to the park of several significant pollution sources, makes air quality of special and compelling interest to park management.

Model of Key Drivers

Natural drivers and anthropogenic stressors affecting air quality on the park are described in the Introduction, section B. Stressors to air quality are depicted in the three general ecosystem models, and in the "Surface Factors" model developed to support the set of "Pathways" models used in the MACA attributes identification process (Figures 4, 5, 6, and 7).

Monitoring Questions and Approach

MACA has in place a comprehensive air-quality monitoring program. This program utilizes EPA methods, protocols and standards to track gaseous pollutants, visibility, acid- and toxic-deposition, and fine particles.

Management Implications

Air quality data provides park management with diverse and detailed information on several extant threats recognized as being important to the park. This information provides an important tool for park management to diversely pursue protection of park resources through continued efforts to address air pollution issues in public and legal forums.

14. Fish Diversity in the Green and Nolin Rivers

Problem Statement and Justification

Mammoth Cave National Park (MACA) incorporates reaches of both the Green and Nolin Rivers, together with diverse tributary streams and springs, within its boundary. The Green River reach is functionally divided into three general zones (an impoundment zone, a transition zone, and an up-stream fluvial zone) with respect to impoundment effects from Lock & Dam #6. The park's reach of the Nolin is largely an impoundment zone caused by Lock & Dam #6., These reaches of the two rivers support a notably diverse ($\geq$ 80 species; Cicerello and Hannan 1991) assemblage of fresh-water fish species. Fish constitute a significant, diverse biological and functional component of the river ecosystem. Trends in fish diversity may serve as a useful and ecologically broadly-integrated indicator of potential shifts in the condition of the river ecosystem as it responds to anthropogenic actions. In addition, fish are presumed to play a central role in the reproductive success of the diverse mussel fauna found in the Green River.

The park's reaches of the Green and Nolin Rivers are subject to several potentially strong anthropogenic stressors. These include dam impoundment effects, on-going mercury accumulation, sport fishing and fish-stocking impacts, impacts from adjacent land use, impacts from park management actions (i.e., enhancement of otter populations on the park), anticipated impacts from flow-release regime alterations at the upstream Green River Dam, and changes in river water quality resulting from implementation of Conservation Reserve Enhancement Program (CREP) projects in upstream reaches of the Green.

Model of Key Drivers

Natural drivers and anthropogenic stressors affecting fish diversity and relative abundance in the Green and Nolin river are described in the Introduction, section B.2., and depicted in the General Aquatic Ecosystem Effects model (Figure 11).

Monitoring Questions and Approach

1. What is the current species diversity and relative abundance of fish species in upstream fluvial, mid-reach transition, and downstream impounded zones of the Green River, and in the park's reach of the Nolin River?
   Fish diversity will be sampled in the Green and Nolin Rivers to provide baseline data on current diversity within the park's reaches of the 2 rivers.
2. What is the trend in species diversity and relative abundance over time (years) in the park's reaches of the Green and Nolin Rivers?
   The fish assemblages in the Green and Nolin Rivers will be annually sampled at several sites to provide diversity index data for trend analysis over time.
3. Are trends the same in all four river zones, or do trends differ among the zones and between the Nolin and Green reaches?
   Fish diversity indices determined for the several sites will be compared for among-site differences and trends.

Management Implications

Monitoring fish diversity in the form of tracking a diversity index (species-richness and relative abundance) and an IBI-metric will yield important information that can contribute to developing future management actions aimed at river resource management and preservation. Diversity trend data would identify actual declines in the resource which would mandate development of management actions to mitigate impacts and suggest research to identify and address specific system threats.
Trend information could support park efforts to remove Lock & Dam #6, and could contribute to evaluation of the changes in water release schedules and regimes recently implemented by the U.S. Army Corps of Engineers at the Green River Dam, along with assessment of CREP program effects on water quality in the Green River.

15. Mussel Diversity in the Green River

Problem Statement and Justification

Mammoth Cave National Park (MACA) incorporates a sizable reach of the Green River within its boundary. This reach is functionally divided into three general zones (an impoundment zone above the dam, a transition zone, and a near-natural up-stream fluvial zone) with respect to impoundment effects from Lock & Dam #6. The reach supports a notably diverse ($\geq$ 51 species) assemblage of native fresh-water mussels, including 7 Federally-listed T & E species (Cicerello and Hannan 1990). Native fresh-water mussels constitute a significant biological and functional component of the river ecosystem, and mussel diversity and abundance may serve as a broad ecological indicator of potential shifts in the condition of the river ecosystem as it responds to anthropogenic actions. Mussels, as filter-feeding organisms, may broadly and diversely respond to many factors that effect water quality, flow regimes, and silt-loading. Mussel distribution may also be influenced by the distribution and abundance of fishes within the river ecosystem, as fish are thought to play important roles in mussel reproduction and distribution.

The mussel fauna of the park's reach of the Green River is subject to several potentially strong anthropogenic stressors. These include dam-caused impoundment effects, mercury accumulation, competition from exotic Asiatic Clam and Zebra Mussel, impacts from adjacent land use, impacts from park management actions, anticipated impacts from flow-release regime alterations at the upstream Green River Dam, and the unknown effects of changes in river water quality resulting from implementation of Conservation Reserve Enhancement Program (CREP) projects in upstream reaches of the Green.

Model of Key Drivers

Natural drivers and anthropogenic stressors affecting mussel diversity in the Green River are described in the Introduction, section B.2., and depicted in the General Aquatic Ecosystem Effects model (Figure 11).

Monitoring Questions and Approach

1. What is the current species diversity and relative abundance of fresh-water mussel species in upstream fluvial, mid-reach transition, and downstream impounded zones of the Green River?
   Mussel diversity will be sampled in three zones of the Green River to provide baseline status and diversity index data.
2. What is the trend in species diversity and relative abundance over time (years) in the park's reaches of the Green River?
   Mussel diversity will be sampled annually in three zones of the Green River and diversity indices analyzed over years to evaluate possible trends in mussel diversity.
3. Are trends in mussel diversity and abundance the same in all three river zones, or do trends differ among the zones over time?

Mussel diversity indices determined for the three zones will be compared among sites and over time.

Management Implications

Monitoring mussel diversity in the form of tracking a diversity index (species-richness and relative abundance) will yield important information that can contribute to developing future management actions aimed at river resource management and preservation.
Information on mussel diversity and relative abundance will contribute to the park's efforts toward conservation of Federally-listed mussel species in the Green River.
Diversity, abundance and trends data would help identify actual declines in the resource which would mandate development of management actions to mitigate impacts and suggest research to identify and address specific system threats.
Trend information for native populations of selected mussel species could contribute to assessing the operational success of the park's mussel culture facility and re-stocking program for reared T & E mussels into the Green River.
Trend information could support park efforts to remove Lock & Dam #6, and could contribute to evaluation of the changes in water release schedules and regimes recently implemented by the U.S. Army Corps of Engineers at the Green River Dam, along with possible contribution to assessment of CREP program effects on water quality in the Green River.

16. Muskrat Predation Impact on Mussel Diversity in the Green River

Problem Statement and Justification

Mammoth Cave National Park's reach of the Green supports a notably diverse ($\geq$ 51 species) assemblage of native fresh-water mussels, including 7 Federally-listed (T & E) species (Cicerello and Hannan 1990). Native fresh-water mussels collectively constitute a significant biological and functional component of the river ecosystem. Mussels, as filter-feeding organisms, may broadly and diversely respond to many factors that effect water quality, flow regimes, and silt-loading. In addition, the Federally-listed species constitute a special biological resource for the park, and impose specific monitoring responsibilities upon park management. Mussel distribution and abundance may reflect predation by native muskrats within the river ecosystem, as muskrats are one of the few animals that prey extensively on mussels. Aside from direct impact by predation on native mussels, muskrat may indirectly impact native mussels via removing Asiatic clams--an abundant exotic invasive species that competes with native mussels. Muskrats have been found to practice size- and species-selective predation on mussels and clams and have been shown to alter the species composition in an area (Convey et al. 1989, Hanson et al. 1989, Neves and Odom 1989, Jokela and Mutikainen 1995, Zahner-Meike and Hanson 2001). In some areas, muskrats have been implicated in destroying mussel beds (Van Cleave 1940), and are probably retarding the recovery of, or further threatening, endangered mussel populations (Neves and Odom 1989, Hoggarth et al. 1995, Zahner-Meike and Hanson 2001).

Model of Key Drivers

Natural drivers and selected anthropogenic stressors affecting mussel diversity in the Green River are described in the Introduction, section B.2., and depicted in the General Aquatic Ecosystem Effects model (Figure 11).

Monitoring Questions and Approach

1. What is the current impact of muskrat predation (as manifest in shell middens) on fresh-water mussel species in upstream fluvial, mid-reach transition, and downstream impounded zones of the Green River?
   Quantitatively sample mussel-shell middens in the Green River to establish current and near-historical species-specific frequencies of muskrat predation on mussels.
2. What is the trend in predation rates over time in the park's reaches of the Green River?
   Periodically sample and monitor mussel species frequencies in selected middens.
3. Are trends in muskrat predation the same in all three river zones, or do trends differ among the zones over time?
   Periodically compare species frequencies among middens and over 3 sites (zones).

Management Implications

Muskrat predation impact data will contribute to the park's understanding of mussel assemblage dynamics within the Green River.

General predation impact data and data on the possible preferential selection of Asiatic Clam by muskrat will contribute to the park's efforts toward conservation of Federally-listed mussels in the Green River.
Predation impact data will contribute to park management evaluation of management actions, including proposed enhancement of river otter populations on the park.

17. Green River Benthic Macroinvertebrate Community IBI

Problem Statement and Justification

Mammoth Cave National Park includes a significant reach (approx. 26 miles) of the Green River. This river is a well-described and well-documented centrum for aquatic biodiversity. The park's reach hosts a large diversity of fishes, mussels, and other invertebrates. The park's reach of the Green is also subject to diverse and serious threats from many sources (see Adjacent Land Use and Water Quality protocol justifications). Benthic macro-invertebrates ("BMIs"), including many insect larval stages and assorted crustacean, nematode, annelid and mollusk species, are well-known to be sensitive to many different chemical pollutants and seemingly small-scale changes in water temperature and dissolved Oxygen. BMI assemblage structure, species richness, and distribution patterns in a water-body can provide diverse and sensitive indication of chemical and physical threats acting on aquatic systems. Tracking BMI assemblages over time using an "Integrated Biological Index" (IBI) approach has been demonstrated to be a useful and effective way of monitoring the state or condition of aquatic ecosystems. An extant BMI IBI protocol is in limited implementation on the park. This protocol will be reviewed for adequacy of sampling design and selection of appropriate methods by USGS-BRD in FY 2004 or FY 2005.

Model of Key Drivers

Natural drivers and anthropogenic stressors affecting the aquatic ecosystem are described in the Introduction, section B.2., and depicted in the General Aquatic Ecosystem Effects model (Figure 11).

Monitoring Questions and Approach

1. What is the invertebrate (excluding mussels) community response to acute and chronic changes in water quality and quantity in the Green River? *[Note: Obtained via the Ohio Community Invertebrate Index (an IBI)]*
   Perform BMI IBI sampling on the Green River. BMI data will be analyzed in correlation with water-quality data to provide a composite picture of aquatic ecosystem condition.

Management Implications

Monitoring data will provide park management with habitat assessment that will contribute to conservation of endangered mussel species.

Monitoring data will contribute to park efforts leading to the conservation of endangered Kentucky cave shrimp (via effects on cave river habitat and food resources) and endangered bats (via effects on food resources).

The IBI will provide park management with information on the on-going impacts of flow regime alterations and future restoration of free-flow conditions.

PART 3. DATA MANAGEMENT SYSTEM AND INTEGRATION WITH MONITORING

A. Introduction

As development and implementation of MACA's LTEM program progresses, staff and cooperators will be collecting an increasing amount of data on the various attributes selected for monitoring. A data management system is required to ensure these observations are accurately stored and provided to decision makers (and others) in a timely and coherent fashion. Data management is more than simply entering records into a computer. As pointed out by Tessler and Gregson (1997) computers increase ones ability to manage larger data sets but computerized data sets, " . . . are uniquely susceptible to accumulating errors through careless handling, systematic problems, and poor security." The Natural Resources Inventory and Monitoring Guideline (NPS-75) notes that many data sets have been " . . . rendered useless because of inconsistency in collection . . ." (i.e., before any record was ever entered into a computer). As such, an effective data management approach is interwoven throughout all phases of a monitoring program. It provides quality assurance (QA) and quality control (QC) measures beginning with data collection and ensures records will be accurate, available, and complete well into the future.

An objective of the LTEM program is to develop a functional data management approach that incorporates service-wide data standards and guidelines. It will take advantage of the data management tools made available by the Inventory and Monitoring Program and the successes and lessons learned by other NPS prototype programs. A formal data management plan will be developed based upon the Draft Data Management Protocol (Tessler and Gregson 1997) and other data management guidelines as they become available.

B. Data Management Responsibilities

To be effective, data management must be a collaborative process with defined roles and responsibilities. At MACA, Information Technology Staff have primary responsibility for installing, servicing, and maintaining computer hardware and software applications, as well as network maintenance and security. MACA LTEM staff includes an ecologist/data manager that will coordinate management of working and archived data sets with project managers (i.e., lead scientist for each protocol). Additional responsibilities will include coordinating database design, data set integration and security, QA/QC oversight, and data dissemination. Project managers will have primary responsibility for data collection, entry, verification, and validation. QA/QC measures will be developed by the Data Manager to assist in this endeavor. Reporting and analysis will be a collaborative process between project managers and the LTEM Program Coordinator with technical assistance provided by the LTEM Data Manager and LTEM Geographic Information System (GIS) Manager.

During the database design phase specialized assistance may be sought from a Data Systems Programmer/Analyst. This individual would assist the LTEM Data Manager with technical development of the data management system and Data Management Plan. This position/assistance would be temporary in nature and once terminated, the LTEM Data Manager would be responsible for future system operation.

C. Data Management System/Approach

A fundamental component of the MACA LTEM program's data management system will be a database structure comprised of MS Access 2002 (XP)[1] databases containing data tables, data entry forms, and summary reports. Like the Prairie Cluster Prototype LTEM Program, MACA LTEM's overall data management approach will be modular in that a functional, stand-alone database will be designed for each protocol with a "centralized" graphic user interface for integrative purposes (DeBacker et al. 2002). Among other benefits, this approach allows data management to progress in tandem with protocol development. In addition, data entry forms and QA/QC safeguards can be individually tailored to meet the needs and abilities of the project manager.

Nested within the modular approach, a set of standardized core tables will be developed for recording of metadata (i.e., sampling location, sampling event, and observer). Field name, size, data type, etc. will be standardized according to service-wide standards and a set of these tables will be duplicated and included in each protocol database. Their design will be conducted in close collaboration with the GIS Manager to ensure integration. Common look up tables will also be developed to increase consistency across databases where possible. In short, every reasonable effort will be made to increase integration among data sets within the LTEM program, as well as, network and service-wide inventory and monitoring databases.

To facilitate integrative analyses, an MS Access based front-end user interface (Graphic User Interface) will be developed whereby archived protocol data sets can be pulled together based upon user requests (Figure 17). This approach allows for integrative analyses to occur by multiple parties without compromising the integrity of archived data sets or requiring redundant storage. This user interface would be an obvious vehicle for export of data sets to service-wide, network, and other database systems.

[1] NPS standard for desktop database applications.

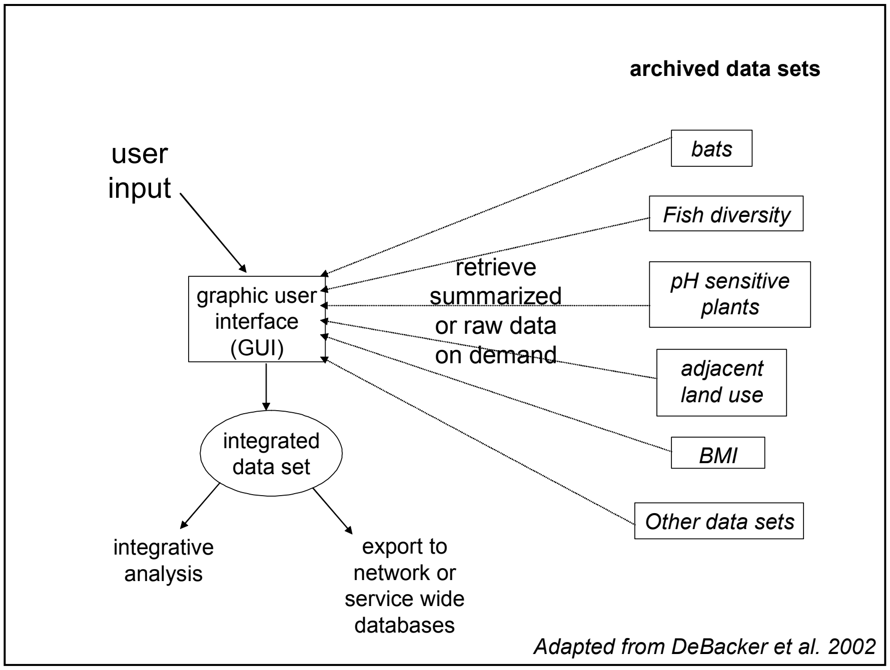

Figure 17. Conceptual diagram of data integration process.

D. Quality Assurance/Quality Control Procedures

As noted earlier, implementation of data QA/QC procedures begin at the time of data collection. As such, each protocol will address measures to ensure consistency and completeness in data collection procedures. Data entry will commence as soon as practicable following collection. Data entry should be conducted by someone familiar with the data collected and methods utilized to reduce the likelihood of erroneous transcription errors. Individuals will possess an acceptable level of proficiency/familiarity with MS Access prior to working with LTEM databases.

Well-designed data entry forms are an integral component to data management QA/QC procedures. Forms will be designed collaboratively by the LTEM data manager and project managers to address individual abilities and complexity of the specific data sets. Key fields will be utilized to prohibit duplicate entry of records. Pick lists and value limits will be used to standardized data values, limit the possibility of errant keystrokes, and detect observation or transcription error. Preferably unified data entry forms will be utilized as opposed to requiring the user to toggle through multiple forms (i.e., a location form, core data form, etc.). Such an approach will improve the QA/QC process by allowing the user to review the full compliment of data for an observation prior to submission. Forms can also be designed similarly to field data forms via this approach. This will not only simplify data entry but also data verification (i.e., comparing entered data to field data form values for accuracy).

Due to their familiarity with the individual data sets, data verification and validation (i.e., checking data for logic errors such as a pH value > 14) will primarily be the responsibility of the project managers. Simple aggregate queries will be housed within each of the protocol databases to assist in this endeavor. Once the computerized records are cross-checked with the original field data for accuracy and reviewed by the project manager for logic errors, the data set will be submitted to the data manager for storage and archival. Copies of the field data sheets will also be archived.

E. Data Archival and Storage

Data protection from loss or corruption is a critical component of data management (Tessler and Gregson 1997). MACA LTEM workstations are connected via a local area network, which is maintained by MACA Information Technology Staff. This system is secured via log-in password protections and controls on user privileges. In addition, because storage media fail and even unintentional corruption of data sets does occur, LTEM databases will be archived and stored in multiple locations. An archival schedule will be established for each protocol.

Appendix A

Significant Natural Resources at Mammoth Cave National Park based on Four Categories

NATURAL RESOURCES SIGNIFICANT TO ENABLING LEGISLATION	NATURAL RESOURCES SIGNIFICANT TO OTHER LEGAL MANDATES/POLICY	NATURAL RESOURCES SIGNIFICANT TO PERFORMANCE MANAGEMENT GOALS	NATURAL RESOURCES SIGNIFICANT FOR OTHER REASONS
Green and Nolin Rivers specifically mentioned in park EL. Cave streams specifically mentioned in park EL. Forest old growth and diversity specifically mentioned in park EL. Caves (formations) specifically mentioned in park EL.	**ESA listed species: 6 mussel species, Indiana and gray bats, bald eagle, Kentucky cave shrimp, crystal darter fish (historic), dragonfly, and Eggert's sunflower. Federal Cave Protection Act. Green River State listed as ONR water. Green River State listed as Wild and Scenic River. Green River State designated use WQ limits and TMDL's (ONR). Cave streams State listed as ONR water. Cave streams State designated use WQ limits and TMDL's (cold water aquatic and ONR). Wetlands (as mapped and yet to be delineated). Clean Air Act (Class I Airshed). State listed species (NPS Policy). EO exotic species.**	**Water quality and aquatic ecosystem health, exotic plant control, disturbed lands, air quality, T&E species, and vital signs.**	**Biodiversity of: surface aquatic, cave aquatic, surface terrestrial, soils, and cave terrestrial ecosystems.** [e.g., Green River: 82 fish, 192 macroinvertebrates, 51 mussels. Species diversity of cave streams; 3 fish, shrimp, crayfish, invertebrates, and microbes. Significant block of relatively undisturbed forest ecosystem: plant species diversity (over 1,300 species of flowering plants including 84 species of trees). Significant habitat types: "Big Woods" (300 acres of old growth), glades, bogs, river islands, sinkholes, hemlock hollows, barren remnants, upland swamps, sandstone/limestone cliff-lines, and cave entrance ecotones.]

Appendix B
Resource Management Issues/Questions at Mammoth Cave National Park

Priority	Management Issues	Significant Natural Resources Impacted	Management Questions	Potential Indicators	Potential Management Actions
HIGH	ADJACENT LANDUSE IMPACTS Adjacent landuse impacts are from agriculture, conversion of farm land to residential properties, commercial development, Lock and Dam #6, Green River Dam, oil drilling, CSX railroad, and I-65 routine runoff).	Air quality & water quality & quantity. Light pollution. Viewshed, noise. Aquatic ecosystems (terrestrial and cave), and terrestrial vertebrates. Native plant community structure.	How is adjacent landuse changing? How are local landuse changes affecting park resources? At what rate are we losing green-space, viewsheds, adjacent to park? What impacts do light and noise pollution have on natural resources? Are exotic species being introduced from and maintained by adjacent lands? How is adjacent landuse affecting surface and cave water quality in the park? How are the cave ecosystems affected by water quality issues on private lands within the park's watershed? What are the impacts to aquatic and terrestrial T & E species? What contaminants do we receive from each landuse, and what are the consequences for aquatic biota, including microbes? Is there an increase on the park in exotic and native predators that thrive in fragmented habitats? What affect does forest fragmentation have on terrestrial vertebrates?	Changes in trends of air and water quality factors. Landuse maps. Viewshed maps. Cave aquatic communities, T & E species populations, cave riparian communities, songbirds, herps, and avian or mammalian predators.	Active participation in local zoning and development. Seek conservation easements (eg. local land trust). Seek protected legislation. Best Management Practices, NRCS Farm Conservation Plans, Forest Stewardship Program, Habitat Improvement Program, and public education.
HIGH	EXOTIC PLANT MANAGEMENT	Native veg. Native wildlife Native plant composition, invertebrate community, bats, birds, and amphibians.	Are "new" exotics invading park? What is the rate of spread? Are exotics affecting T&E's? What are impacts of exotics on natural associations? What acreage is being treated? What is the effectiveness of existing garlic mustard control? Is the occurrence and density of exotic plants greater along horse/hiking trails? Is atmospheric deposition of ammonia/NOX exacerbating exotic plant populations? What is the impact of utility corridor and road right-of-ways management? Is roadside grass fertilization impacting water quality in surface waters and cave streams and is this fertilization exacerbating exotic plant growth? Is parkway tree removal encouraging exotic plant invasion and densities?	RANGE MAPS. PERMANENT VEG. PLOTS (INCLUDING DISTURBED AREAS) T&E PROXIMITY MAPS. Garlic mustard populations. Exotic and native plant diversity, distribution and abundance. Invertebrate abundance and presence, amphibian and avian diversity and abundance.	Control and eradication program. Education of landscape designers, nurseries & local govts. Training personnel, contractors. Contracting and special use permits. Use local genotype seed.

Appendix B (Cont.)
Resource Management Issues/Questions at Mammoth Cave National Park

Priority	Management Issues	Significant Natural Resources Impacted	Management Questions	Potential Indicators	Potential Management Actions
HIGH	*FIRE MANAGEMENT*	**Native veg. Water Exotics Plant composition of barren and savanna habitats. Bats, small mammals, reptiles and amphibians, insects, and birds. Eggert's sunflower and other rare plants.**	**Are fuels building up enough to pose a serious threat to resources? Is fire suppression a serious risk to resources? Wwhat effects will fire have on natural resources? (Spelled out in FMP). Is fire a risk inside/outside the park? What are the impacts of prescribed and wildland fires on birds, rare and listed plants, bats, reptiles, amphibians, insects, and small mammals? What fire frequency and timing is most appropriate to benefit barren and savanna habitats, species diversity and abundance, and control invasive plants? Does prescribed fire benefit Indiana bat maternity habitat?**	**Selected species, fuel (composition, loading, structure) maps. Fire occurrence. Plant community composition and abundance within barren and savanna habitats. Bat use of burned vs. unburned habitats for foraging, roosting, and as maternity habitat. Presence and density of fauna in burned vs. unburned habitats. Exotic plant populations.**	**Public info, education, FMP, prescribed fire, hazard fuel reduction, post-treatment vegetation manipulation**
HIGH	*AIR QUALITY* Ozone Visibility Deposition Toxins **Dry and wet acid deposition Radioisotopes Nitrification** **(MACA called this issue "Air Resources Management")**	**Air Visibility Vegetation Water Wildlife Soils, microbes, vegetation community with emphasis on ginseng, snails, snail-feeding birds, salamanders and other amphibians, fish, and mussels. Swamp and forest - savanna - prairie ecosystems. Green River aquatic ecosystem, bats, and cave aquatic fauna.**	**Are high levels of O_3 impacting plants or other resources? What toxins are present in air and are they being transported through ecosystem? How is visibility being impacted over time? Does deposition pose a threat to natural resources? Is acid deposition leaching soil nutrients such as calcium, magnesium, potassium, sodium and ammonium? If rain acidification is leaching soil nutrients, is this affecting plant community composition and exotic plant densities? Is acid rain producing dissolution of soil aluminum and if so, are aluminum concentrations in surface and cave streams adversely affecting fish, shrimp and mussels? What are impacts of acid rain to soil pH, amphibians, and foliage? How is mercury bioaccumulation via atmospheric loading from coal-fired power plants affecting the cave and surface ecosystems? How are arsenic, fluoride, beryllium, lead, selenium, and radioisotope loading from coal burning affecting cave and karst ecosystem? What affect does anthropogenic ozone and nitrates produced by coal burning and internal combustion engines have on the growth of sensitive plant species and is this adversely affecting forest and barren plant community composition? What are the effects of using alternative fuels?**	**O_3 sensitive plants. Water quality. Sediment, snow. Levels of positively charged soil nutrients. Soil pH, composition of soil microbial community, plant species sensitive to soil pH and calcium levels such as ginseng. Soil and water aluminum concentrations. Condition of fish and mussel gills. Snails and salamanders. Levels of mercury in water, soil, air and throughout the food chain pyramid, with an emphasis on flora and fauna at the upper trophic levels, such as bats, mussels, piscivorous fish and cave aquatic fauna. Arsenic, fluoride and radioisotope levels in water, soil and flora such as ferns. Growth rates and densities of black cherry, tulip poplar, blackberry, etc.**	**Public info, education, influence permit review and local/state/federal air quality regulations and planning.**

Appendix B (Cont.)
Resource Management Issues/Questions at Mammoth Cave National Park

Priority	Management Issues	Significant Natural Resources Impacted	Management Questions	Potential Indicators	Potential Management Actions
MEDIUM	**VISITORS USE IMPACTS** **(Visitor use impacts to both the cave terrestrial and surface ecosystems)**	**Native terrestrial animals/plants. Water quality, caves. Bats, cave crickets, beetles, woodrats, cave salamanders, oxygen, and carbon dioxide levels. Impacts from cave tours: relative humidity, temperature, plant community composition, trail erosion, sedimentation, and poaching of medicinal plants.**	**Are heavily used trails causing impacts to natural resources? Are visitor tours of caves impacting the caves' terrestrial fauna, and atmospheric conditions? Are current levels of horse use introducing and exacerbating exotic plant trends or having an impact on poaching of medicinal plants? Is the current level of horse/bike use impacting surface and cave stream water quality…specifically coliform bacteria levels? What are the impacts from back-country camping?**	**Soil erosion. Soil compaction, vegetation damage (cliff face). Abundance and frequency of cave bats, cave crickets, beetles, woodrats, and salamanders. Carbon dioxide levels. Densities of exotic plants along horse trails. Trail erosion rates. Ginseng and goldenseal poaching along horse trails. Presence and density of horse coliform bacteria in surface and cave streams near horse trails.**	**Limit or restrict access. Education – Outreach. VERP. Establishment of "Off Limits" times or caves if necessary.**
HIGH	*WATER QUALITY* *(MACA called this issue "Water Resources Management")*	**Surface water Aquatic life Recreation Aesthetics Cave waters**	**Is water quality impaired, as per designated use standards? Is water quality being affected by atmospheric deposition? What are the long-term water quality trends? Define water quality maxima during flood pulse activity. Is roadside grass fertilization impacting water quality in surface waters and cave streams?**	**WRD core parameters plus CPN parameter list. Riparian birds. Herps, macroinvertebrates. Phytoplankton and zooplankton, fish, and high levels of nitrogen, phosphorous, potassium and chlorophyll A compounds in surface and cave waters.**	**Initiate mitigative research and action to correct problem. Establishment of groundwater protection zone. Establishment of National Wild/Scenic River. Work with Ky Oil/Gas to ID and properly abandon wells within Green River Flood plain. Continue work with Ky Department of Transportation in BMP installation along transportation corridors. Complete Water Resources Mgt. Plan. Complete parking lot runoff project (Project 187).**

Appendix B (Cont.)
Resource Management Issues/Questions at Mammoth Cave National Park

Priority	Management Issues	Significant Natural Resources Impacted	Management Questions	Potential Indicators	Potential Management Actions
MEDIUM	**POACHING AND THEFT OF NATURAL RESOURCES**	**Ginseng, goldenseal, galax, bloodroot, deer, pitcher plant, turkey. Medicinal plants, mussels, flowering plants, and cave formations.**	**What resources are at threat from being poached? What is the current distribution of those species? Is poaching occurring? Quantify the impact of poaching and theft on medicinal plants, flowering plants, and mussels. How effective are remote sensors in reducing poaching of medicinal plants? What effect would increased back-country ranger presence have on poaching?**	**State lists of poached plants/animals, distribution maps, Ginseng, bloodroot, goldenseal, orchids, and other charismatic flowering plants. Mussel bed disturbance and populations.**	**Magnetometers. LE/resources protection. Propagation and replanting of poached plants. Use of dyes and micro-trace markers. Public education. Remote sensors. Increase back-country patrol.**
HIGH	**NATIVE TERRESTRIAL PLANT MANAGEMENT AND MONITORING**	**Native terrestrial plants Oaks, dogwood, American chestnut, butternut, and American elm. Ginseng and goldenseal.**	**What is the distribution of native plants? What is the condition of native plant health? Should the park monitor oak tree populations to determine if declining oak disease is affecting the oaks? Should we monitor for dogwood anthracnos? Should we monitor ginseng and goldenseal populations susceptible to poaching? Should we collect seed and grow ginseng, goldenseal, butternut, and elm in a greenhouse setting in order to augment populations? Should we inventory for butternut, elm, and chestnut? Are there correlations between atmospheric pollutants and plant disease? What are the impacts of parkway tree-cutting and roadside fertilization?**	**Distribution maps, Vegetation maps, Vegetation plots Oak tree densities and death rates. Dogwood abundance and death rates. Ginseng and goldenseal populations. Presence of chestnut, butternut, and elm.**	**Planning, recreational use restrictions. Explore discontinuation of parkway tree-cutting and roadside fertilization. Encourage use of native plants along management roadsides. Train park staff in the recognition of plant diseases, pests, and exotic plants. Develop a predictive model for distribution of ginseng and butternut. Conduct routine surveys for plant diseases.**
MEDIUM	**NATIVE ANIMAL SPECIES (0VER) POPULATION MANAGEMENT**	**Native plants/ animals, deer, beaver, coyote (In the recent past: raccoon) (Possibly in the future: turkey)**	**What is the current population and condition of the population? Are animal populations causing impacts to other natural resources? Is the lack of hunting pressure in the park sustaining an artificially high deer population? Are deer over grazing the plant community and adversely affecting plant diversity and reproduction?**	**deer, beaver, coyote Vegetation browse lines and density of deer-preferred plants.**	**Build deer exclosure(s).**

Appendix B (Cont.)
Resource Management Issues/Questions at Mammoth Cave National Park

Priority	Management Issues	Significant Natural Resources Impacted	Management Questions	Potential Indicators	Potential Management Actions
MEDIUM	DISTURBED AREA REHABILITATION (includes "Cave Ecological Restoration" here too)	Native plants, water quality, habitat, natural landscape, soil erosion, and cave-dwelling bats.	Presence of exotics. Are disturbed lands the seed source for exotics? Are there contaminants within the disturbed lands? Have natural drainage patterns been altered? Are natural habitats altered? Are disturbed lands providing habitat for exotic animals? Will restoration of cave atmospheric conditions make a cave more attractive to bats?	Historic documentation, maps, photos. Water quality, soil loss, and exotic plants. Re-establish target community. Paleontological record (to determine historic bat use of caves). Cave-dwelling bat population sizes and distribution.	Use local genotype seed. Restore/rehab disturbed lands. Monitoring of construction activities (for spread of exotics). Proper disposal/reuse of materials. Vegetate bare soil (erosion control). Replace old cave entrance gates, doors and walls with bat-friendly gates. Put air locks on manmade cave entrances.
HIGH	THREATENED AND ENDANGERED PLANT MANAGEMENT	Eggert's sunflower, State-listed plant species	What is the distribution of plants of concern? What is the condition of the population of plants of concern?	Distribution maps. Condition assessment.	Seed collection, propagation, fire management, and habitat restoration.
HIGH	PEST AND HAZARD MANAGEMENT (also called: "EXOTIC DISEASES, PESTS AND HAZARDS MANAGEMENT")	Aging and diseased trees. Native terrestrial plants/animals Forest plant community composition. Snags and Indiana bats. Oak, hemlock, pine, butternut, and American chestnut. Woodrats.	What impact does the removal of aged and diseased trees have on other natural resources? Are forest pests spreading into the park and damaging resources? How did the introduction of chestnut blight, butternut canker, gypsy moths, and Dutch elm disease affect the forest tree composition? Is the cutting of hazardous trees affecting Indiana bat roosting habitat? Are there environmental conditions exacerbating southern pine beetle or hemlock woolly adelgid outbreaks? Is the Allegheny woodrat population being negatively impacted by density increases in the raccoon roundworm parasite?	Bat populations Forest pest plots Densities of deciduous trees. Parkway ecotone habitat used as roosting habitat for Indiana bats. Densities of roundworm-infected raccoons (larvae and eggs can be detected in raccoon feces).	Hazard tree removal, save some snags for habitat Create a seed or tissue culture bank for potentially extirpated plants. Develop Integrated Pest Management plans.

Appendix B (Cont.)
Resource Management Issues/Questions at Mammoth Cave National Park

Priority	Management Issues	Significant Natural Resources Impacted	Management Questions	Potential Indicators	Potential Management Actions
HIGH	**EXOTIC ANIMAL MANAGEMENT**	**Birds Small mammals Native terrestrial plants/animals Native mussels, herps, Kentucky cave shrimp, aquatic cave invertebrates, cavefish, and aquatic surface macroinvertebrates.**	**Are feral/domestic cats impacting natural resources? Are feral/domestic dogs impacting natural resources? Are "new" exotics invading park? Are zebra mussels identified in Green River Lake migrating down stream and affecting native mussels? Will Green River flow release modifications affect the invasion of zebra mussels and *Corbicula* (Asiatic clam) densities? Do exotic rainbow trout adversely affect the endangered Kentucky cave shrimp and other aquatic cave biota?**	**Presence of zebra mussels and densities within native mussel habitat. Densities of *Corbicula* within native mussel beds. Presence and abundance of feral/domestic cats and dogs. Cave shrimp populations. Nest predation rates by exotic animals. Macroinvertebrate assemblage.**	**Research the effects of stocking trout, and modifying river flow. Public education. Inspect motor boats. Write Integrated Pest Management plan.**
HIGH	**NATIVE TERRESTRIAL ANIMAL MANAGEMENT AND MONITORING**	**Native terrestrial animals Rafinesque big-eared bats and other non T&E bats, deer, turkey, raccoons, songbirds, woodrats, herps, and ruffed grouse. Surface and subsurface invertebrates.**	**What is the distribution of native terrestrial animals? What is the condition of native terrestrial animals? Is the Maple Springs bat house sufficiently engineered to provide appropriate maternity habitat for Rafinesque big-eared bats, or would another structure be more effective? Are deer and turkey populations having an adverse impact on the vegetation community? Have ruffed grouse moved into the park? Status of rare invertebrate populations? What is the impact of cowbirds on native songbirds? Should we be planting chestnut trees to benefit woodrats and other animals? Should we restore prairie, barren, and savanna habitats to benefit grassland birds? What is the status of herpetofauna in the park?**	**Utilization of the Maple Springs and Bat Conservation International structure by Rafinesque big-eared bats. Other park structures. Deer and turkey populations. Vegetation community composition. Evidence of a prominent browse line. Presence and abundance of ruffed grouse. Cave beetles, odonates, other inverts (e.g., dead bat numbers in hibernacula, arachnids). Herpetofauna population trends and diversity.**	**Erect and test various artificial bat roosts. Attempt to restore natural bat roosts by protecting and promoting large cavity-forming trees. Listing of rare species. Cowbird trapping, education of the public, minimize fragmented habitat within park. Increase ruffed grouse habitat through prescribed burning.**
HIGH	**THREATENED AND ENDANGERED ANIMAL MANAGEMENT**	**Mussels (7 species in the Green and Nolin Rivers), Indiana and gray bats, bald eagle, Kentucky cave shrimp, crystal darter fish. Rare dragonflies and cave beetles. State-listed animal species.**	**What impact do river otters have on endangered mussels? What impact is Lock and Dam #6 having on mussel diversity and abundance? What impact will Green River Dam water-release modifications have on mussel diversity, reproduction and abundance? What impact will 29 newly proposed power plants in Kentucky have on Indiana bats, mussels, Kentucky Cave shrimp and bald eagles? What impact will the Green River Green River Conservation Reserve Enhancement Program program have on mussel diversity and abundance? Are bat hibernation habitats unprotected? Is Indiana bat maternity habitat adequate? What are <u>mercury</u> levels in T & E species' tissues? What, if any, are the impacts of <u>mercury</u> on populations?**	**Mussel diversity and abundance. Population levels of Indiana and gray bats. Monitor bat cave microclimates. Locate and monitor Indiana bat summer roosts. Number of eagles over-wintering in the park. Kentucky cave shrimp presence and abundance. Crystal darter presence and abundance. Presence/absence of rare invertebrates. Abundance of insects consumed by endangered bats.**	**Riparian buffers. Removal of Lock and Dam #6 on the Green River. Closer approximation of natural flow regimes on the Green River by modifying water releases at the Green River Dam. Bat-friendly cave gates.**

Appendix B (Cont.)
Resource Management Issues/Questions at Mammoth Cave National Park

Priority	Management Issues	Significant Natural Resources Impacted	Management Questions	Potential Indicators	Potential Management Actions
LOW	GEOLOGIC RESOURCES MANAGEMENT	Cave speleothems	What are the impacts of human visitation on fragile geologic resources such as stalagmites and stalactites?	Lamp flora, lint, speleothem damage.	Lighting design modification, limit or restrict access, establishment of “Off-limits” caves, and vacuuming of lint.
HIGH	NATIVE AQUATIC ANIMAL MANAGEMENT AND MONITORING	Mussels in the Green and Nolin rivers, fish populations, river otter, riparian birds, waterfowl, benthic invertebrates, zooplankton, crayfish, cave fish, beaver, muskrat, and base level cave community including endangered Kentucky cave shrimp. Green & Nolin River riffle habitat and aquatic flora and fauna, and hydrology of both surface rivers and cave streams.	Do river otters affect muskrat populations and mussel diversity and abundance? Will wintering bald eagle numbers be affected by reduced visibility? How will zooplankton, benthic invertebrates, fish, mussels, and crayfish be affected by removal of Lock and Dam # 6 and water release modifications from Green River dam? At what rate does recovery occur following removal of the dam? How significantly is Lock and Dam # 6 affecting surface and subsurface aquatic habitat, species diversity, and populations of flora and fauna?	Muskrat, riparian bird and waterfowl densities, fish, mussel, and benthic invertebrate and crayfish diversity, frequency and abundance. Plankton. Beaver abundance. Water quality, water temperatures, oxygen, and suspended solids.	Habitat alteration (enhancement). Riparian buffers. Removal of Lock and Dam #6 on the Green River. Closer approximation of natural flow regimes on the Green River by modifying water releases at the Green River Dam.
LOW	NATIVE AQUATIC PLANT MANAGEMENT AND MONITORING	wetlands vegetation	How may we best manage aquatic vegetation in Sloan’s Crossing Pond?	Abundance and distribution of aquatic vegetation in Sloan’s Crossing Pond.	Reduction of cattails and other vegetation. Ecological restoration of Sloan’s Crossing Pond.
MEDIUM	HUNTED AND TRAPPED SPECIES MANAGEMENT	Fish community and native mussels. Edible mushrooms.	What impact is fishing harvest having on fish diversity and abundance? Is fishing affecting mussel reproduction and recruitment? What impact is mushroom hunting having upon mushroom populations and other natural resources?	Fish community diversity and abundance. Reproduction of mussels reliant upon game fish hosts. Mushroom diversity and relative abundance.	River and backcountry patrol. If significant impacts are detected, then limit or eliminate mushroom collecting.

Appendix B (Cont.)
Resource Management Issues/Questions at Mammoth Cave National Park

Priority	Management Issues	Significant Natural Resources Impacted	Management Questions	Potential Indicators	Potential Management Actions
HIGH	REINTRODUCTION OF EXTIRPATED ANIMALS	River otter, ruffed grouse, extirpated mussels, crystal darter fish.	What affects will the reintroduction of river otter have on native mussel populations? Have ruffed grouse or river otters returned to the park? Does sufficient ruffed grouse habitat exist in the park? Have some mussel species been extirpated from the park? Has the crystal darter been extirpated from the park?	River otter population, muskrat densities and muskrat midden composition, mussel populations, ruffed grouse population, and crystal darter population.	Propagation and reintroduction of extirpated mussels. Reintroduction of crystal darters, river otters, and ruffed grouse.
HIGH	REINTRODUCTION OF EXTIRPATED PLANTS	American chestnut, showy lady slipper orchid.	Can chestnut, and showy lady slipper orchid be successfully reintroduced into /enhanced in the park's forest ecosystem?	Survival rates of planted trees and flowers. Changes in woodrat, squirrel, deer, and turkey populations and distribution.	Propagation and reintroduction of extirpated species. Revision of extant reintroduction program. Establishment of seed banks, tissue culture, and greenhouse(s).

Appendix C

Current Monitoring and Survey Activities at Mammoth Cave National Park, Kentucky

CURRENT ACTIVITIES	SOURCE OF MONITORING AND SURVEY DATA
Water Quality Monitoring	Joe Meiman, Science and Resources Management
Monitoring aquatic macroinvertebrates in surface waters	Dr. Scott Grubbs, Dept. of Biology, Western Kentucky University
Mussel monitoring in the Green River	Dr. James Layzer, USGS/BRD Tennessee Cooperative Fisheries Unit
Fish monitoring in the Green River and its tributaries	Dr. Philip Lienesch, Dept. of Biology, Western Kentucky University
Aquatic fauna monitoring in subterranean streams	Dr. William Pearson, Biology Dept., University of Louisville
Allegheny woodrat monitoring	Steven Thomas, Science and Resources Management --LTEM
American chestnut monitoring	Science and Resources Management staff in cooperation with University of Tennessee
US EPA Source Drinking Water monitoring within Mammoth Cave National Park	Dr. Chris Groves, Western Kentucky University
Fire effects monitoring	GRSM Fire Effects Team; and Michele Webber, Science and Resources Management--LTEM
Forest health monitoring (FHI/FHA)	John Anderson, Kentucky Division of Forestry; and USFS
High intensity ginseng monitoring	Michele Webber, Science and Resources Management--LTEM
Muskrat and river otter monitoring	Dr. Joe Clark, University of Tennessee
Cave cricket monitoring	Kurt Helf, Science and Resources Management-LTEM
Surprising cave beetle monitoring	Kurt Helf, Science and Resources Management-LTEM
Bat monitoring	Kentucky Department of Fish and Wildlife Resources; USFWS; and Steven Thomas, Science and Resources Management-LTEM
Air quality monitoring (surface)	Bobby Carson and Johnathan Jernigan (ARD), Science and Resources Management
Cave atmospheric monitoring	Johnathan Jernigan, Science and Resources Management-LTEM
Vernal pool amphibian monitoring	Dr. Floyd Scott, Austin Peay State University
Breeding bird monitoring	Kentucky Department of Fish and Wildlife Resources; USGS/BBS; and Steven Thomas, Science and Resources Management-LTEM

Appendix D

Criteria for MACA's Round 1 Sorting

For 31 March 2003 meeting:

Step 1. Pathways ranking /prioritization

Criteria: 1). Management significance/relevance/interest
--How important is the understanding of this pathway to MACA management? (Score: 0 = little or no importance, 1 = important, 2 = extremely important)

2). Ecological significance/relevance/importance to system understanding
--How valuable/worthwhile is this pathway in understanding system interconnections leading into the cave ecosystem? (Score: 0 = not related to cave ecosystem, 1 = peripheral to cave ecosystem, 2 = central to cave ecosystem)

Step 2. Attributes ranking within priority pathways

Criteria: 1). Ecological significance/relevance/importance to system pathway understanding

Average these two subcriteria scores

a). How important is the attribute in understanding or tracking ecosystem pathway function? (Score: 0 = not important, 1 = of little importance, 2 = important, 3 = extremely important)

b). How central is the attribute in controlling or driving ecosystem pathway function? (Score: 0 = on periphery of pathway…plays almost no role in pathway function, 1 = plays a minor role in pathway function, 2 = plays a moderate role in pathway function, 3 = central to pathway function)

2). Robustness (attribute relates to multiple pathways; "more bang for buck")
a). How closely linked is the attribute with other attributes in other pathways? (Score: 0 = not linked at all, 1 = a few minor/weak links, 2 = a few major/strong links, 3 = many major/strong links)

Appendix D (cont.)

Criteria for MACA's Round 1 Sorting (Continued)

Average these three subcriteria scores

3). Management significance/relevance/interest

a). How important/urgent is the understanding of this attribute to MACA management? (Score: 0 = not important, 1 = of little importance, 2 = important, 3 = extremely important)

b). How well will monitoring of this attribute provide data needed for making management decisions (internal and external)? [*a priori*] (Score: 0 = not at all, 1 = poorly at best, 2 = moderately, 3 = extremely well)

c). How well will monitoring of this attribute provide an accurate evaluation of the outcomes of one or more management decisions? [*posteriori*] (Score: 0 = not at all, 1 = poorly at best, 2 = moderately, 3 = extremely well)

Average these three subcriteria scores

4). Monitoring efficacy/feasibility

a). How much is currently known about the attribute? [i.e., should this be in the research or monitoring category?] (Score: 0 = almost nothing known…research, 1 = little known…research, 2 = some known… research? or monitoring?, 3 = much known…monitoring)

b). How difficult will it be to monitor this attribute? [Score: 0 = impractical and extremely difficult, 1 = impractical and inconvenient, 2 = practical, 3 = not difficult (easy) and convenient]

c). Will you be able to collect data for this attribute at the same time as (and in the general vicinity of where) you are collecting data for one or more other attributes? (Score: 0 = no, 1 = maybe one collateral dataset, 2 = maybe two or three collateral datasets, 3 = many collateral datasets)

Appendix E

Lower Ranked Pathways at End of Round One, Step 1 in the Mammoth Cave Prototype Ranking Process

PATHWAY
1) Cave Air
2) Other Visitors Guano +
3) GR Fish Community
4) Muskrat
5) GR Herps/Amphibians
6) Aquatic Birds
7) Grazer – Deer
8) Grazer – Turkey
9) Land Birds
10) Vernal Pools

Appendix F

Research Catalog Items and Future Monitoring Targets (No specific order):

Cave River Microbe Assemblage inventory & definition
Guano deposition rate/composition/distribution research
Guano-dependent Invertebrate Communities research
Egg-Predator beetle impacts on cricket pop/recruitment
Mussel Host-fish identification research
Soil Invertebrate inventories & distribution/association research
Inventories of predators associated w/ soil invertebrates
"BMI" Winged-adult inventories & distribution research
Vernal-pool amphibians inventories & population research
Vernal-pool Invertebrate assemblage inventories & research
FPOM/POM-contaminants relationships baseline data for MACA?
Forest community composition- selected stands {USFS/KYDF coop work}
Fire effects monitoring – barrens restoration sites, etc.
Exotic/invasive plant species pops & impacts (coop w/ EPMT efforts)
Deer pops & grazing impacts (ID resources to focus on?)
Cave-"entrance" plant communities (ref cricket & woodrat resources/diet)

Appendix G

MACA Ecosystem Pathway & Attribute Prioritization Process

ROUND 2 RESULTS—FINAL MATRIX

Cave River	Cave Nutrients (Cave Terrestrial)	Specific Vegetation	Surface Aquatic Communities
Cave Water Quality + Quantity	Cave Air Temp. & Relative Humidity	Ozone-sensitive plant species (Native populations)	Mussel Community
Cave River Fauna (Fish, Shrimp, Crayfish, Inverts IBI)	Cave Cricket population parameters	"pH-sensitive" plants/communities w/Soil Chemistry	Green River Fish Communities
Surface River & Stream Water Quality + Quantity	Woodrat population parameters	Pests & Pathogens assoc. w/ Elms, Butternut, Hemlock, Chestnut populations, and rare tree restoration	Benthic macroinvertebrates (w/ Particulate Organic Matter ref. specified questions & threats)
	Cave-dwelling Bat populations		Muskrat impact on mussel community
	Egg-Predator Beetle pops & distribution		

<u>Stressors to be (or being) monitored</u>: Adjacent Land Use, Air Contaminants, Water Contaminants